The validation and use of a three dimensional goniometry system to investigate lumbar motion in healthy subjects and low back pain patients undergoing manual mobilisation

Thesis

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THE VALIDATION AND USE OF A THREE DIMENSIONAL GONIOMETRY SYSTEM TO INVESTIGATE LUMBAR MOTION IN HEALTHY SUBJECTS AND LOW BACK PAIN PATIENTS UNDERGOING MANUAL MOBILISATION

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Abstract

This study of lumbar spinal kinematics in healthy subjects and low back pain patients had three defined aims: The first aim was to investigate the lumbar spinal kinematics in healthy subjects during 6 gross movements and 4 functional activities using a newly developed electromagnetic measurement system and to establish a database for three dimensional kinematics with which subsequent patient data could be compared. The second aim was to investigate the effects of low back pain on lumbar spinal motion during 6 gross movements and 4 functional activities and hence contribute to the conceptual framework related to low back pain. The third aim involved a randomised controlled clinical trial to determine the immediate effects of low velocity mobilisations on pain, pattern and range of movement in acute/subacute low back pain patients and hence enhance the theory and practice of orthopaedic manipulative therapy.

A series of validation tests were carried out on the measurement device (3 Space Isotrak) in order to determine its accuracy and precision. The device had a random error of 0.03 degrees and a systematic error of 0.45 degrees with a percentage linearity of 1.24%. Good linearity was shown up to ± 80 degrees whereafter the systematic error gradually increased. However, significant cross-talk between angulation recording channels limited the working range further to ±70 degrees.

One-hundred healthy subjects in the age range 20 to 77 were recruited from a diverse population in Edinburgh. Excursion data for 5 age cohorts (males and females) were obtained over a 6 months period. These excursion data were obtained during a total of 10 tests (6 gross movements and 4 functional tasks).

The normative data revealed that healthy subjects had a gradually decreasing lumbar flexibility with age in both females and males with females showing greater lumbar flexibility then males. Regression analysis indicated that lumbar mobility was negatively associated with an increase in age and mass whereas height was not associated with lumbar flexibility and females showing greater flexibility than males.

Statistical analysis was carried out, using independent t-tests, to test the hypothesis of no differences between healthy subjects and patients. A significant decreased mobility ($p<0.05$) in 5 out of the 6 gross, primary movements and 3 out of 4 functional, primary movements was found. Only small changes were observed in the associated, gross coupled movements. However, during the execution of the functional tasks significant differences ($p<0.05$) in the excursions of the coupled movements were recorded.

Forty-one patients with uncomplicated low back pain were recruited into a randomised controlled trial. Using a blocked randomisation procedure, patients were assigned to an intervention group (n=20) and a delayed intervention group (n=21) where the former received the treatment immediately after the first measurement and the latter after 1/2 hours rest. Both groups received a low velocity mobilisation based on the Maitland concept. The mobility of the patients was measured 3 times within a time period of 2.5 hour. In addition, a visual analogue scale was used to record changes in pain or discomfort.

An ANOVA-design was used to test the differences in excursion values between and within the two groups and over the 3 tests occasions. Post-hoc analysis revealed no significant

increase in mobility when the intervention group, after the treatment, was compared to the delayed intervention group before the treatment. Descriptive analysis of visual analogue scale scores revealed a reduced mean score after intervention. However, non-parametric statistical analysis (Wilcoxon, signed rank test 2-tailed) revealed no significant reduction in pain levels experienced after a mobilisation intervention.

The value of 3 dimensional motion recording in lumbar spine assessment is discussed. The clinical trial demonstrated that the newly developed system for 3 dimensional motion measurement can effectively measure small changes in lumbar spinal flexibility. It is easy to use in a physiotherapy out-patient clinic and can be successfully used to assess and evaluate three dimensional lumbar flexibility mobility in LBP-patients. The appropriateness of this newly developed system for clinical use in physiotherapy is debated.

The lack of immediate effects after a lumbar mobilisation in the treatment of low back pain are discussed and potential implications for the conceptual framework regarding the use of low velocity mobilisations in the treatment of low back pain are provided.

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Contents

1. Review of the literature related to low back pain research

1.1 Background to the study

The measurement of spinal movement is a key factor in the diagnosis and assessment of low back pain. Although this procedure forms a routine part of clinical practice it has received relatively little attention in comparison to other parts of back pain management such as treatment procedures and low back pain prevention measures.

Within the physiotherapy profession, orthopaedic manipulative therapists (OMT) are primarily concerned with the restoration of full, painfree functional movement in the spine and the extremities. Manipulation (high velocity thrusts) and mobilisation (low velocity thrusts) techniques form an important part of the therapeutic procedures available to them; it is therefore incumbent on the physiotherapy profession in general and the OMT-practitioner in particular to constantly evaluate and adjust their therapeutic procedures.

Numerous attempts to design and introduce simple, easy to use measurement devices for low back mobility have been made over the past 30 years. However, the spine is a complex three-dimensional structure and consequently spinal movements should incorporate a three-dimensional aspect, in order to establish a movement pattern. This pattern of movement can be recorded in addition to measurements of excursions and ranges of motion. In doing so, a more comprehensive assessment of the complex compensatory movements of the spine could be established.

There is a need to provide the clinician with a simple, clinical manageable measuring device which allows him/her to fully assess, functional three dimensional back motion routinely in

the clinic. However, little clinical research has been published to investigate the exact relationship between three-dimensional movement and low back pathology.

This project aims to establish a routine three-dimensional measure of lumbar spinal motion and to use it to evaluate the normal motion of the lumbar spine. In addition, the project aims to use this method to evaluate lumbar spinal motion in people with low back pain before and after a low velocity mobilisation treatment by a physiotherapist.

This chapter comprises a review of the literature on low back pain and its effect on low back mobility. Furthermore, it will give an overview of the literature pertaining to mobilisation and physiotherapy and identify that restoration of mobility is a common goal of physiotherapy for patients with acute/subacute low back pain.

As low back pain is a cosmopolitan health problem and in order to facilitate a dialogue on low back pain it is appropriate to clarify some of the commonly used definitions and expressions used in low back pain research.

1.2 Concepts and definitions used in low back pain research

Low back pain (LBP) is one of the most common conditions presented to the health care professional (Waddell and Turck, 1992). In most cases a specific lesion responsible for LBP cannot be determined. Hence it is usually not possible to make a precise pathological diagnosis or even to identify the anatomical origin of the pain experienced (Nachemson, 1976). It has been suggested by White and Gordon (1982) that for as many as 85% of back pain episodes, the cause of pain is unclear, thus leaving the vast majority of patients with LBP without a specific diagnosis, resulting in a condition that has been described as an

"illness in search of a disease" (Williams and Hadler, 1983).

Low back pain can be regarded as a term used to describe a range of symptoms but even then there is no one agreed definition on the symptoms of low back pain (Evans and Richards, 1996). From the inability to identify the aetiology of back pain there has arisen an abundance of hypotheses of causation, some of which are used as a theoretical basis for treatment (Evans and Richards, 1996). Bernard and Kirkaldy-Willis (1987) identified the dubious reliability, sensitivity, specificity, and utility of many common examination and laboratory tests used in the diagnosis of back pain as major contributing factors to the failure to identify the aetiology of low back pain.

In an extensive meta-analysis on low back pain, Evans and Richards (1996) reported that the differing definitions of low back pain employed usually refer to the pain experienced between the inferior angle of the scapula and the gluteal folds. However, some authors define low back pain in more specific terms by relating it to the lumbar area of the spine or by specifying the different segments related to the lumbar vertebrae. For the vast majority of those with low back pain the symptoms are not related to any specific pathological process which is evidently the cause of their pain i.e. those with "non-specific"(or common) LBP.

Hart et al (1995) found that in a study on physician office visits for low back pain, in the period 1989-1990, 56.8% of LBP-patients received a diagnosis of "non-specific"-LBP. Apart from pain, clinical signs and symptoms may include spasm of the para-spinal musculature, paraesthesia and in particular stiffness, leading to restrictions of spinal motion in one or more directions.

Evans and Richards (1996) pointed to differences in the use of the definition of LBP. Some health care professionals include, within the definition of LBP, those individuals with sciatica (or other radicular) symptoms, whilst others specifically exclude this group from the definition. The symptoms of nerve root compression cross a wide spectrum of severity, and are frequently accompanied by LBP. Frymoyer (1988) reported that one percent of patients with acute LBP (ALBP) have sciatica, which is defined as

> "pain in the distribution of a lumbar nerve root, often accompanied by neuro-sensory and motor deficits" (Frymoyer, 1988).

Some of the group of patients with sciatica and low back pain have a serious underlying spinal disease such as tumours or infections (Clinical Standards Advisory Group, 1994, CSAG). At the less severe end of the spectrum patients may have LBP with sciatic-like symptoms but no evidence of nerve root involvement (CSAG, 1994). Those patients with clear signs and symptoms of nerve root compression are excluded from the definition of LBP by many health care professionals. However, people with LBP and a lesser severity of sciatic-like pain, are not necessarily recognised by all practitioners as sufficiently clinically different from the rest of those with non-specific LBP as to warrant exclusion from this definition (Evans and Richards, 1996). A proportion of those defined as having LBP may, therefore have mild symptoms from specific pathological causes.

Before knowledge of low back disorders can be increased and different types of treatment can be evaluated, it is imperative that a system of classification is developed. Several systems of classification of LBP do exist. However, currently no standard system of evaluation exists nor is there general agreement on the definition of basic terminology on LBP. In the International Classification of Diseases (National Centre for Health Statistics, 1968) the terminology most commonly used is the indexing of hospital records and morbidity statistics; e.g. number 728.10 is assigned to lumbalgia.

Nachemson and Anderson (1982) proposed a system of classification which relates terminology to symptoms. All definitions are based on the patient's own description. Each such symptom- related diagnosis can be verified by simple clinical findings. The duration and onset of the disease is given as a prefix. In parenthesis, after the symptom diagnosis, additional information can be included, as for example radiographic results or the evaluators own suggestion e.g. acute lumbago (traumatica). The prefix "acute" and "subacute" differ with respect to the onset of pain (immediate or slow onset), while acute and chronic differ with respect to the duration of the symptoms (chronic = over 3 months). This classification system is in general use in Scandinavia, especially Sweden where it has been used by clinicians and researchers for several years.

Waddell (1982) analysed 900 patients referred to an orthopaedic outpatient clinic and suggested that, using clinical history and examination LBP-patients could be separated into three broad diagnostic groups; (1) simple mechanical low back pain, (2) nerve root pain, and (3) serious spinal pathology. The term "mechanical" was used simply to indicate that the pain is related to physical activity. This classification, although rather broad and not disability related, is primarily used for diagnostic triage of acute low back pain problems.

It was the system of choice for two recently published reports on acute LBP i.e. Bigos et al (1994) and Clinical Standards Advisory Group (CSAG) report on LBP (1994).

Frymoyer (1988) categorises low back pain using the duration of the symptoms as a criterion. This will be discussed further in the next section. In contrast, Delitto et al (1995) proposed three orders of classification to be used: stage 1 for patients where the therapeutic goal is symptom relief, stage 2 where symptom relief and quick return to normal function are encouraged, and stage 3 for selected patients who must return to activities requiring high physical demands and who demonstrate a lack of physical conditioning necessary to perform the desired activities safely.

This plethora of classification systems implies that the terminology and nosology of low back pain is neither "standardised nor validated" (Spitzer et al, 1987). This lack of uniformity in definition, diagnosis and classification is undoubtedly both a major barrier and a challenge to LBP-research (Foster, 1998).

1.3 Defining acute and chronic low back pain

The most commonly used classification of the pain experienced by LBP-patients is developed by Frymoyer (1988) and is based on a description of the pain duration. This author classifies pain either as acute (0-6 weeks), sub-acute (6-12 weeks) or chronic (>12 weeks).

The Agency for Health Care Policy and Research (AHCPR) in the U.S.A defines acute low back pain (ALBP) as:

> "activity intolerance due to lower back or back related leg symptoms of less than 3 months duration" (Bigos et al, 1994).

The point of transition from acute low back pain (ALBP) to chronic low back pain (CLBP) varies from author to author but has been commonly described as pain of more than 7 weeks (Walsh, 1992) or up to more than 3 months duration. (Frymoyer, 1988; Koes et al, 1995; Bigos et al, 1994). The majority of researchers however, have used three months of continual LBP as a cut-off point to define a chronic condition. This cut off point is further based upon epidemiological data suggesting that 90% of acute pain episodes of LBP are fully recovered in six weeks (Dillane et al, 1966). A similar recovery rate figure was reported by Anderson and Deyo (1997). In this prospective study 49,000 LBP-patients between 20 and 64 years of age were included. Fifty-seven percent of patients recovered in 1 week, 90% in 6 weeks and 95% after 12 weeks. At the end of 1 year 1.2% remained work-disabled.

The use of the duration of pain as the only parameter for classification of LBP has been challenged in recent years. Von Korff et al (1993) introduced a more dynamic model for classification of LBP. These authors pleaded for the inclusion of the intensity of pain, its

duration (including that due to recurrences) and functional disability into the classification of low back pain. Another weakness of a classification of acute and chronic LBP based on duration of pain alone is the greater contribution of psychological and social factors in the latter, and in the processes whereby pain becomes a chronic state (Waddell, 1987a, Waddell, 1987b and Waddell, 1992). Haldeman (1990) in his Presidential Address to the North American Spine Society stated: "The close correlation between psychosocial factors and patients with chronic back pain is now conclusive, although the relative importance of various factors has yet to be worked out". Bigos et al (1991) identified several risk factors for reporting acute back pain at work in a prospective study conducted on 3,020 aircraft employees of a Boeing Company in Western Washington. These authors concluded that even in acute LBP a complex set of factors influenced the rate of reporting back injuries. Of particular interest was the observation that individuals who "hardly ever" enjoyed their work were at significantly greater risk of back complaints when compared with individuals who "almost always "enjoyed their work. Multiple other psychosocial factors such as litigation, workers compensation, loneliness and coping skills have all been considered important(Bigos et al, 1991).

Magnusson et al (1998) investigated the specific characteristics of trunk motion associated with long-term dysfunction caused by low back pain of variable origin. This study reported that pain avoidance behaviour becomes the norm in CLBP. This may lead to increased dysfunction when muscles and ligaments are not used to their ultimate limits. If the functional Range of Motion (RoM) is limited because of pain for a long period of time, the actual RoM will become decreased as the soft tissue shortens and strength decreases. The impairment then may be a result of these consequences of disuse, rather than a result of the initial injury. Frymoyer, (1988) reported that after three months, only 5% of LBP-patients

had persistent symptoms, yet it is this population that accounts for 85% of the cost in terms of compensation and loss of work due to low back pain. As chronicity increases the pain becomes increasingly dissociated from the original basis, and there is often little objective evidence of any remaining nociceptive stimulus (Foster, 1988). The assessment of disability and psychological status becomes increasingly important in chronic LBP and is especially important when choosing the appropriate treatment and patient management protocol. In contrast in acute low back pain patients physical factors dominate.

Waddell (1986) stated that the aim in assessment of physical impairment is to provide objective medical evidence that is both reproducible and unequivocal. Measures of spinal mobility and strength are adding considerably to the biomedical understanding and in the future they may provide a more absolute measure of lumbar impairment in people with acute low back pain (Mayer et al, 1985)

1.4 Recurrence rate

An important factor in describing LBP is the recurrence rate (Croft et al, 1998). Although LBP is a common, self-limiting disorder with a high rate of spontaneous recovery within 4-6 weeks, most first time sufferers will experience a relapse of their symptoms. Several authors have reported recurrence rates for LBP ranging between 42% and 72% (Papageorgiou and Rigby, 1991; Torptsova et al, 1995; Szpalski et al 1995; Brown et al, 1998; Linton et al, 1998). These relapses tend to be more severe and of longer duration then the first attack (Flor and Turck, 1984). Biering-Sorensen (1983) in a prospective study of LBP in a general population concluded that the more recently and frequently a person has experienced LBP the more liable he/she will be to experience LBP again. The high significance of previous LBP as a predictor of future symptoms has also been demonstrated in other longitudinal studies (Rowe, 1969; Troup et al, 1981).

Despite the fact that the recurrence rate is an important indicator of the severity and the disability caused by back pain during the life time of the patient, very few clinical studies adequately describe the recurrence rate of LBP over long-term follow-ups or use it as an outcome parameter (Von Korff and Saunders, 1996).

In a recent study by Croft et al (1998) it was suggested that LBP should not necessarily be seen as a "one-off" condition or even an episodic complaint, but that perhaps a longer term view of the condition would be more appropriate.

One may conclude from the literature that recurrence of symptoms is a common feature of low back pain and that the patient may retain some physical impairments after one attack of LBP which may make recurrence of symptoms more likely. Adequate measurement methods to identify these physical impairments are currently unavailable.

1.5 Defining physical impairment and disability in low back pain

Assessment of the severity of low back pain injuries has been based on diagnosis, pain, disability, physical impairment and capacity for work (Waddell and Main, 1987).

Impairment and disability are fundamentally different concepts and it is important to draw a very clear distinction between them (Waddell and Turck, 1992). Physical impairment is defined as

> "an anatomical, pathological or physiological abnormality of structure or function leading to loss of normal bodily ability"

and disability is the resulting

> "diminished capacity for everyday activities and gainful employment" (Waddell and Maine, 1984; Waddell, Alan and Newton, 1991).

Bowling (1991) further described disability as

"the degree to which an individual can function and is independent of pain status" (Bowling, 1991).

Waddell (1992) defined physiological impairment as the

"health care professional's assessment of objective abnormalities".

Limitations observed in LBP sufferers include restrictions in pelvic flexion, total flexion and extension, lateral flexion, straight leg raising, bilateral active straight leg raising and sitting up from lying. Spinal tenderness also occurs. Waddell argues that such impairments are more appropriately termed "physiological impairments", since they are reversible in the case of acute low back pain. He concluded that assessment of impairment is based on objective structural limitations and is solely the responsibility of medical and allied health professionals. In contrast disability rating and compensation awards, are administrative or legal responsibilities, not medical responsibilities, and are based both on the patient's report of disability and the physician's assessment of impairment. Financial compensation concentrates mainly but not exclusively on incapacity for work (Waddell, 1987a).

There is now general agreement between a number of research groups around the world that disability is best assessed by the patient's report of restriction in activities of daily living: bending and lifting, sitting, standing, walking, travelling, socialising, sleep, sex and putting on or taking off footwear (Waddell and Maine, 1984).

In conclusion it is important to distinguish between impairment and disability. Physical impairment is objective structural limitation; disability is the resulting loss of function during normal daily activities. Impairment is a tissue damage-concept in contrast to disability which is a task-based concept (Waddell and Turck, 1992).

1.6 Relationship between pain, disability and impairment.

Many authors have demonstrated that acute low back pain (ALBP) subjects have impaired lumbar spine motion (Mayer et al, 1984; Pope et al, 1985; Marras and Wongsam, 1986; Marras et al, 1995; McGregor et al, 1995; McGregor et al, 1997). In acute LBP the degree of pain reported is associated with the clinical findings of impairment on examination and to the disability experienced by the sufferer (Waddell, 1992). For chronic LBP these relationships became increasingly less well defined with increasing chronicity of back pain.

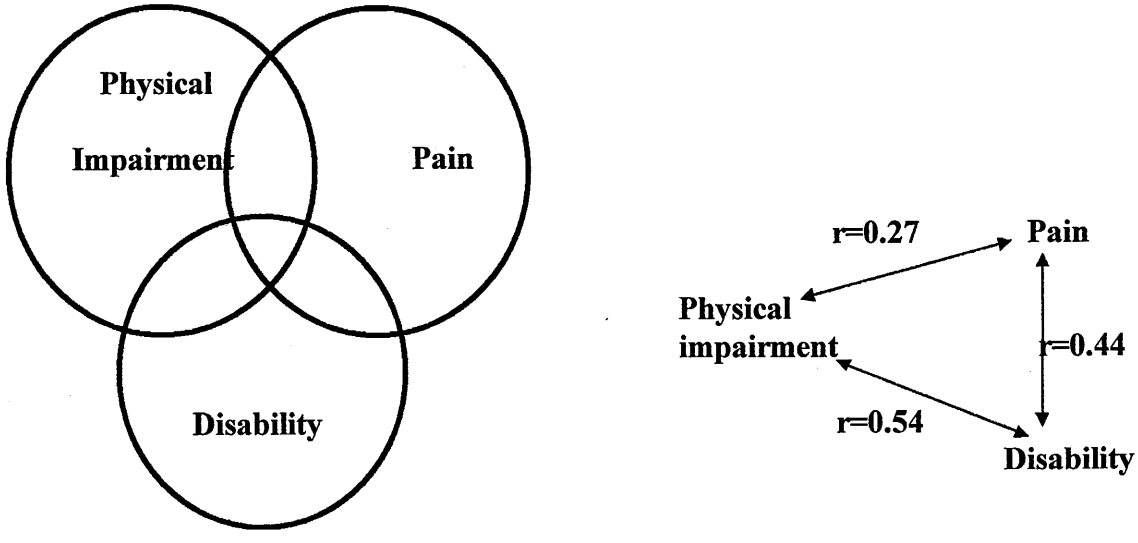


Figure 1.1 The quantitative relationship found in chronic low back pain between the clinical presentation of pain, disability and objective physical impairment and the correlation coefficients (r) between them (Waddell, 1987b).

Waddell's work indicates that the correlation between pain, impairment and disability is low in chronic LBP. Thus knowing a chronic low back patient's pain level does not necessarily allow one to predict the severity of physical impairment or the degree of disability an individual is experiencing. Therefore the assessment of impairment and functional ability is valuable in acute/subacute low back pain but less useful for chronic low back pain.

The disparity between pain, impairment and disability in chronic LBP is clearly illustrated by observing recent trends in the epidemiology of LBP.

The prevalence of disability due to LBP has escalated over the past 15 years (Waddell, 1992) but there is no evidence that the incidence, prevalence or nature of LBP has altered during this time. Waddell (1986) further stated that the rise in disability is a phenomenon associated almost entirely with Western nations or developing nations which are adopting a Western lifestyle. He referred to the newly introduced orthopaedic services in rapidly developing countries such as Oman, which are inundated with patients looking for treatment for LBP. The striking observation in Oman is that although low back pain is common, there was very little actual disability before the introduction of Western medicine. Patients are crippled by polio, tuberculosis or thoraco-lumbar fractures, but virtually no one goes to bed, stops daily life, or is permanently disabled by simple LBP (Waddell, 1986). This suggests that disability is mediated by social factors. The rate of disability associated with LBP exceeds that of all other forms of chronic conditions with ensuing disability (Frymoyer et al, 1991). Hazard et al (1991) also concluded that chronic LBP complaints frequently correlate poorly with apparent pathology and with measured physical capacities. Further, McGregor et al (1998) investigated the relationship between chronic low back patients' signs and presenting symptoms and objective measurements of motion. Certain factors, such as diagnosis, pain characteristics, symptom severity, and level of disruption, were related to the resulting motion measurements. The strength of these relationships, however were not as strong as anticipated (accounting for 16-45% of the variability). These authors therefore concluded that mobility measurements in chronic LBP-patients are poor indicator of disability. However, they stressed that in the model used no psychological and social factors were considered.

Waddell (1987b) concludes, in his meta-analysis report, with the observation that chronic pain becomes a completely different clinical syndrome from acute pain. Acute and chronic pain are not only different in time scale but are fundamentally different in kind. Acute and experimental pain bear a relatively straight forward relationship to peripheral stimulus, nociception, and tissue damage (International Association for the Study of Pain, 1979). Acute pain and acute disability are generally proportionate to the physical findings i.e. motion characteristics. Chronic pain, chronic disability and chronic illness behaviour in contrast become increasingly dissociated from the original physical basis and there may, indeed be little objective evidence of any remaining nociceptive stimulus. Instead, chronic pain and disability become increasingly associated with emotional distress, failed treatment and adoption of a sick role (Bortz, 1984).

1.7 Epidemiology and cost of low back pain

1.7.1 Prevalence and incidence of low back pain

Several studies have indicated that as many as 60-100% of the Western population will experience LBP during their adult life (Kelsey and White, 1980; Auchincloss, 1983; Walsh 1992). Although most of us will suffer from low back pain or discomfort during our lifetime only 3% will actually seek consultation or treatment. Nevertheless, the numbers involved are still considerable and they make LBP complaints the third largest diagnostic group seeking care from family physicians after heart diseases and rheumatic diseases (Waddell, 1993). Two point two million people consulted their General Practitioner complaining of back pain in 1983 as reported by Wells (1985).

In the United States back pain accounted for 2.8% of all visits to physician as reported by Cypress (1983). This study emphasised differences in resources used by type of physician (Medical Doctors (MD) versus Doctors of Osteopathy, (DO)). MDs used more radiographs (22% versus 10%, respectively) and drugs (62% versus 33%) than DOs but far less physiotherapy referrals (20% versus 83%). Hart et al (1995) reported that there were almost 15 million office visits for "mechanical" low back pain in 1990, ranking low back pain fifth as a reason for all physician visits in the U.S. Low back pain accounted for 2.8 percent of all office visits.

Most studies of LBP are cross-sectional and therefore give information about prevalence (number of patients in a population who have the condition at a certain point in time) rather than incidence (number of new cases over a certain period of time) (Ahlbom & Norrell, 1987). In these studies people with LBP of a longer duration form a substantial proportion of cases. It is unclear from most of the epidemiological studies if the reported figures are

related to patients who have sought treatment for low back pain, were absent from work or merely reporting discomfort without seeking treatment for it.

Low back pain is very prevalent in the Western world. Deyo and Tsui-Wu (1987) in the USA found a point prevalence of seven percent for LBP lasting more than two weeks within an adult population. In the UK a prevalence of 21% for LBP occurring in the previous two weeks was estimated in a study by Wood and Badley (1980). An annual prevalence of 36% was found in a population of 20-60 year olds in a study by Walsh (1992). Croft (1994) found a period prevalence of 39% in one month. Recent prevalence figures on back pain in Britain were published by the Department of Health in the OPCS-survey (1994).This survey reported a similar prevalence rate of 37% in adults over the age of 16 having experienced LBP lasting for more than a day in the twelve months prior to interview. The precise question asked will evidently affect the rate obtained, and much of the variation in prevalence reported is likely to be due to this factor.

Little differences in prevalence rates between men and women were reported (Walsh, 1992; Loesner and Volinn, 1991). Also no marked differences in incidence and prevalence rates in different geographical areas in the UK were reported (Walsh, 1992).

1.7.2 Incidence and prevalence of disability in LBP-patients

Frymoyer and Catsbaril, (1991) reported that in acute low back pain (ALBP) only low job satisfaction appeared to be associated with disability, although it is postulated that stress may amplify the experience of pain. Disability in chronic low back pain was statistically associated with social factors, including low job satisfaction, pending litigation and compensation payments.

Although disability seems more to be associated with chronic low back pain the OPCS survey (1994) identified that 8% of LBP sufferers had spent "most or all " of at least one day in the previous four weeks lying down because of their back pain. The report comments

that this implies that 3% of all adults over the age of 16 spend one or more days lying down because of back pain in a four-week period. The proportion was similar in all age-groups, and in men and women. In addition to those who spent one or more days lying down, the survey found that 30% of back pain sufferers (equivalent to 11% of all adults over the age of 16) had restricted their activities over the previous four weeks because of LBP. Nearly a third of these had done so for the entire four week period. The type of restrictions recorded included being unable to perform usual activities in the home and garden, being unable to play sport and being constrained in mobility.

In the OPCS survey (1994), 63% of respondents had been employed during the previous four weeks, and 6% of these had taken time off work because of back pain in this period. Half of those who took time off work took five days or fewer, a quarter took 20 or more days. Moreover, one fifth of those who were unemployed in the previous four weeks cited back pain as a relevant factor in their being unemployed .

1.7.3 The cost of LBP to the NHS and Society

The escalating costs of LBP to society has primarily been recognised by epidemiologists who have analysed the socio-economic implications of LBP and as a result advocated changes in the management of LBP (Weber and Snook, 1990). The cost of back pain can be divided into NHS expenditure, other health care expenditure e.g. complementary therapy, time off work costs, legal fees and indirect costs e.g. lost employment and corresponding reduction in payment of taxes. It is important to point out that most studies regarding cost information on the use of NHS services do not specify low back pain but merely consider the whole spine when the term "back pain" (including neck, upper back and LBP) is used. The burden, due to back pain in the NHS is considerable, and has risen rapidly over a period of ten years. The medical costs were estimated to be £156 million by the Office of Home Economics of United Kingdom (1985). This had increased to £ 382.7 million in 1993. Back

pain accounted for between 0.93% and 1.15% of the NHS expenditure in 1992/93. More recently two major publications have analysed the cost to society in the UK. These are a recent publication by the York Centre for Health Economics (Klaber-Moffett et al, 1995) and a study published by the Clinical Standards Advisory Group on Back Pain (CSAG, 1994). A summary of their findings is presented in table 1.1

NHS service	CSAG estimated mean costs (millions) 1993	York estimated costs (millions) 1992/3
A&E attendance	£ 17.0	-
Day cases	-	£5.3-£7.0
GP consultation	£130.0	£67.3-99.4
Inpatient	£106.0	£117.4-122.4
Outpatient	£72.0	£12.3-24.3
Physiotherapy	£ 63.0	£24.0-36.0
Prescribed drugs	£48.0	£12.3-£33.5
Radiology	£45.0	£26.7-£60.1
Estimated total Costs Mean (SD)	£480 (£356-£649)	£324 (£265-£382)

Table 1.1 The costs of back pain within the NHS in the period 1992/1993. After Evans and Richards, (1996).

The CSAG-report is based on figures from a variety of epidemiological studies prior to 1994. Its estimates of services usage tend to be higher than the York report (except on the cost of inpatient care). The CSAG-report was completed prior to the York analysis and was based on limited epidemiological evidence. The CSAG refers the reader to the York report, suggesting that these figures should be a more accurate analysis of the costs of back pain.

However, the figures show a broad general agreement. Both surveys reported the highest costs for general practitioner consultations and inpatients management. Physiotherapy treatment costs were placed third.

In addition to these figures Klaber-Moffet et al (1995) estimated the health care costs for complementary therapy (osteopaths and chiropractic) at £89 million and private physiotherapy at £38.6 million.

Between 1986 and 1992, the number of certified days of incapacity due to LBP in Britain rose by 104%, while other causes of sickness rose by about 60% (Klaber-Moffet et al, 1995).

1.8 The use of lumbar spinal mobility measurement in low back pain diagnosis and treatment

Cave drawings in Central Asia as well as paintings and statues found in ancient Aztecs tombs are good illustrations of man's interest in the pattern of his normal and pathological movement since prehistoric times. However, the first systematic investigation of human movement was in the fifteenth century by Leonardo Da Vinci in his "Notes on the Human Body" (Pearcy, 1986). In 1836 Weber & Weber reported on lumbar spinal mobility in 3 post-mortem specimens. Since then several in vitro and in vivo studies have been published on the kinematics of the spine in normals or cadaver studies on normal spines (Tanz, 1953.; Pennal et al, 1972; Hilton et al, 1979; Pearcy et al, 1984; Pearcy. 1985; Buchalter et al, 1986; Putto and Tallroth, 1990; McCollam and Benson, 1993; Dvorak, 1995; Esola 1996; and Schuit et al, 1997).

Remarkably little research has been conducted to determine the exact relationship between lumbar spinal mobility and spinal pathology. This is surprising as clinicians, generally, perform some sort of assessment of movement in attempts to detect pathology or to record the effect of a treatment procedure.

Most of the published studies describe changes in flexion-extension mobility to illustrate differences between LBP-patients and healthy subjects e.g. Mayer et al (1984) and Burton et al (1987). Moreover, the earlier studies have measured spinal mobility clinically with the aid of radiographs consequently the scope of these studies has been limited due the radiation levels.

Advances in the field of rheumatology emphasised the importance of limitation of lumbar spinal movement as a diagnostic criterion. Ankylosing spondylitis in particular has been well researched. This inflammatory condition results in the calcification of the spinal ligaments. Several studies have been published on the limitation of lumbar spinal movement of this disease and how its progression was monitored (Dunham, 1949; Macrae & Wright 1969; Sturrock et al, 1973).

Gianturco (1944) described several types of deviation from the normal pattern of motion in a high percentage of patients but he did not relate this abnormal movement to their respective pathologies

Begg and Falconer (1949) were the first to investigate the possibility of diagnosing spinal pathology, especially the diagnosis of degenerative disc diseases. They described the "disc syndrome", by variations from a normal pattern of 16, 15, 14, 12, and 10 degrees of motion range at the lumbosacral joint and at each successive overlying joint in that order. They also dismissed the lateral bending range of the lumbar spine as insignificant.

During the 1950's four studies were published (Tanz, 1953; Aho et al ,1955; Jirout, 1957 and Mensor & Duvall, 1959) which all reported a decrease in segmental flexion-extension in low back patients. Pennal et al, (1972) using their "point of motion radiographic system" reported a difference in lumbar motion between pathological and normal subjects in 65% of intervertebral joints studied. These studies were all radiographic studies and only evaluated lumbar intervertebral motion (segmental).

The development of more simple and less expensive measurement techniques (described in more detail in chapter 2) came with the publication of more clinical studies where the difference in mobility between normals and LBP-sufferers became more apparent. Mayer et al (1984), reported a reduction in lumbar flexion in chronic low back pain patients. These patients were measured using an inclinometer. Burton (1987), using a flexicurve technique, also found sagittal mobility to be reduced, relative to healthy subjects, in patients with acute low back pain. He also reported that relative hyper-mobility was not unusual. Mellin (1989) suggested that the measurement of lateral flexion (lateral bend) using a tape measuring technique correlates better with the degree of back pain related disability than forward flexion and that lateral flexion would be a more useful clinical measure. Dupuis et al. (1985) and Boden and Wiesel, (1990) used the magnitude of the anteroposterior translation associated with sagittal plane movements as an indicator of vertebral stability.

The first investigations in the three dimensional movements of the low back were performed by a technique known as biplanar radiography. Two studies were found in the medical literature which reported on the effect of low-back pain on lumbar spinal movements in 3 dimensions. Stokes et al. (1981) related narrowed disc space to abnormality of movement and asymmetry of motion was noted in joints with herniated nucleus pulposus. Pearcy (1985) differentiated between patients with back pain alone and with back pain plus nerve tension signs. However, the measurement did not provide more clinically useful information concerning individual patients with this type of back pain. Klein et al. (1991) used discriminant analyses to classify LBP as a function of RoM, isometric extension strength

and electromyography and to discriminate between rowers with and without LBP. These authors used a double inclinometer technique to take RoM measurements of forward and backwards, a tape measure for lateral bending and a double-arm goniometer for axial

rotation. In this study, sensitivity was found to be 66% and specificity 71%, indicating that these techniques may be of limited usefulness for LBP screening and diagnosis. However they concluded that spinal mobility measures can be used to reliably assess changes in lumbar motions.

Since the introduction of three dimensional (3D) goniometers a new standard for LBP measurements has been set. These devices allow the clinician to record a pattern of motion in 3 different directions simultaneously. Hindle (1989) first published a pool of normative data for 3D motion of the low back. By using kinematic patterns this author was able to distinguish between the kinematic movements of normals and pathologic groups. He also stated that this parameter might be able to delineate specific patient groups. However, his method of fixation of the device raises doubts about his conclusions.

Magnusson et al (1998) showed significant improvement in features of movement such as shape, velocity and pattern of motion after a 2 weeks rehabilitation program. This study suggested that the use of a 3 D movement patterns will enable clinicians to observe patients and assess the progress or evolution of active conservative treatment for individual patients.

1.9 Conclusion

Low back pain is a complex condition, difficult to link to underlying pathology.

Episodes of Back Pain can be classified into acute (< 6 weeks) subacute (between 6 and 12 weeks) and chronic (>12 weeks). However acute episodes may recur leading to a chronic condition.

In acute/subacute patients there is a reasonable correspondence between pain experienced and physical impairment with some relationship to the disability produced. In chronic cases psychological factors become more important and the pain and disability are increasingly disassociated from the impairment.

Acute/subacute low back pain has a high prevalence and incidence in the UK.

Physiotherapy treatment of acute low back pain is a major part of service delivery and is likely to continue to place a demand on the physiotherapy community.

Mobilisation (low velocity thrusts) and manipulation (high velocity thrusts) performed by physiotherapists, are likely to be of greatest effect in acute/subacute LBP where psychological factors are minimised. Here the challenge is not to get the patient better as 90% of them recover within 6 weeks regardless of the treatment received, but to reduce the morbidity associated with each episode of low back pain.

In order to establish the effectiveness of a physiotherapy treatment in low back pain an understanding is required of the impairment of lumbar spinal motion caused by

acute/subacute low back pain. The evaluation, in the clinic, of active and passive lumbar spinal motion is part of the routine clinical evaluation methods used by clinicians for the diagnosis and evaluation of treatment procedures in LBP-patients. However, relatively little emphasis has been put on these procedures compared to other areas of back pain management i.e. pain.

Range of Motion measurement has an important role to play as a diagnostic and evaluative criterion for acute/subacute low back pain. It is, together with pain assessment, the dominant parameter used by physiotherapists in LBP evaluation. This criteria has the potential to help the clinician to evaluate and monitor progress in low back pain treatment.

There is a need for further studies on the effects of back pain treatments on lumbar spinal mobility. They are essential to the practice of spinal orthopaedic medicine which has as its primary aim, to assess and treat patient's joint mobility and restore their pain-free range of movement.

2. Measurement of lumbar spinal kinematics

2.1 Introduction

Disorders of the lumbar spine cause certain biomechanical changes in the mobility characteristics of the spine and body (Pope et al, 1979, Jarayaraman et al, 1994).

In order to assess the severity of these changes, plan treatment and assess progress it is necessary to provide objective measurements of spinal mobility (Rothstein, 1985). Furthermore clinical measurements allow effective communication between therapists and doctors, provided the measurements are valid and reliable (Newton and Waddell, 1991).

Current clinical assessment of patients with low back pain usually involves a subjective analysis by the clinician of the patient while they undertake a series of prescribed movements. These visual assessments are often supported by simple one-dimensional measurements of RoM to enable some quantifiable index to be recorded (Pearcy and Gill, 1987).

The prescribed movements are usually carried out in the primary planes of motion i.e. flexion, extension, sidebending and axial rotation (Willems et al, 1996). However movement of the spine is complex and three-dimensional in nature (White and Panjabi, 1978). It would appear then that only three-dimensional measurements systems can give a representative and true picture of lumbar spinal motion (Hindle et al, 1990).

The morphology of the spine dictates its mechanical behaviour. Pathological changes or surgical alteration of the spine's normal morphology inevitably will change the spine's mechanical behaviour (Panjabi et al, 1994). Technical advances in the fields of radiology and imaging have led to a precise description of morphological changes that produce or accompany spinal disorders. Missing are comprehensive non-invasive methods to evaluate

the mechanical behaviour of the normal and abnormal spine in vivo. This mechanical behaviour can best be described with joint kinematics and knowledge of the forces acting on the structures involved. However, as forces are difficult to measure, in vivo clinical studies of spinal biomechanics focus primarily on joint kinematics (Steffen et al, 1997).

Many theoretical bases and experimental techniques have been developed for the kinematic analysis of sophisticated human movement (An and Chao, 1984).

Since the main functions of the musculo-skeletal system are to provide mobility and sustain load it is reasonable to assume that mechanical factors will play an important role in the function and pathology of this system. To determine these mechanical factors, motions and loads must be quantified in precise biomechanical terms (Yamamoto et al, 1989). The forces in the spine are difficult to measure directly but can be estimated using biomechanical modelling. This modelling process is complex and time consuming and therefore does not lend itself to clinical evaluation of the spine (McGill, 1992). Hence clinical effectiveness studies have concentrated on measuring spinal kinematics.

2.2 Joints kinematics

Kinematics is the study of motion without reference to the forces causing this motion (An and Chao, 1984). This fundamental branch of dynamics finds a challenging application in the study of human movement.

Kinesiological measurements are aimed at quantitatively describing the spatial motion of body segments and hence the movements of the joint connecting those segments. The results can be used for the objective determination of the kinematics (the changes of spatial co-ordinates with time) (Allard et al, 1995).

Kinematic measurements of human movement has both basic and applied value in medicine and biology. Gross measurement of motion i.e. forward flexion, extension, sidebending and twisting can be used as a tool for the evaluation of the basic anatomical integrity of the lumbar spine after various surgical or therapeutic treatments (An and Chao, 1984). In addition, kinematic measurements can be used to assess mobility in a range of functional activities.

2.2.1 Terms and Definitions

Agreed terms and definitions are needed for clear and accurate scientific communication. The literature indicates some confusion in this respect. Therefore, to avoid confusion, the definitions to be used in this study are given below.

The following terms and definitions are described by White and Panjabi (1978).

Motion segment: A motion segment is constituted by two adjacent vertebrae and their intervening soft tissues.

Translation: a body is said to be in translation when movement is such that all particles in the body at a given time have the same velocity relevant to some reference.

Rotation: a body is said to be in rotation when movement is such that all particles along some straight line in the body, or a hypothetical extension of it, have a zero velocity relative to some reference.

Degrees of Freedom (df) (figure 2.1): One degree of freedom is illustrated by a rigid body which has the possibility of translating back and forth in either direction along a rigid line. If a given body can rotate back and forth clockwise and counter-clockwise in either direction, that too possesses one degree of freedom. In a three dimensional system a body may posses up to 6 degrees of freedom (3 translations and 3 rotations).

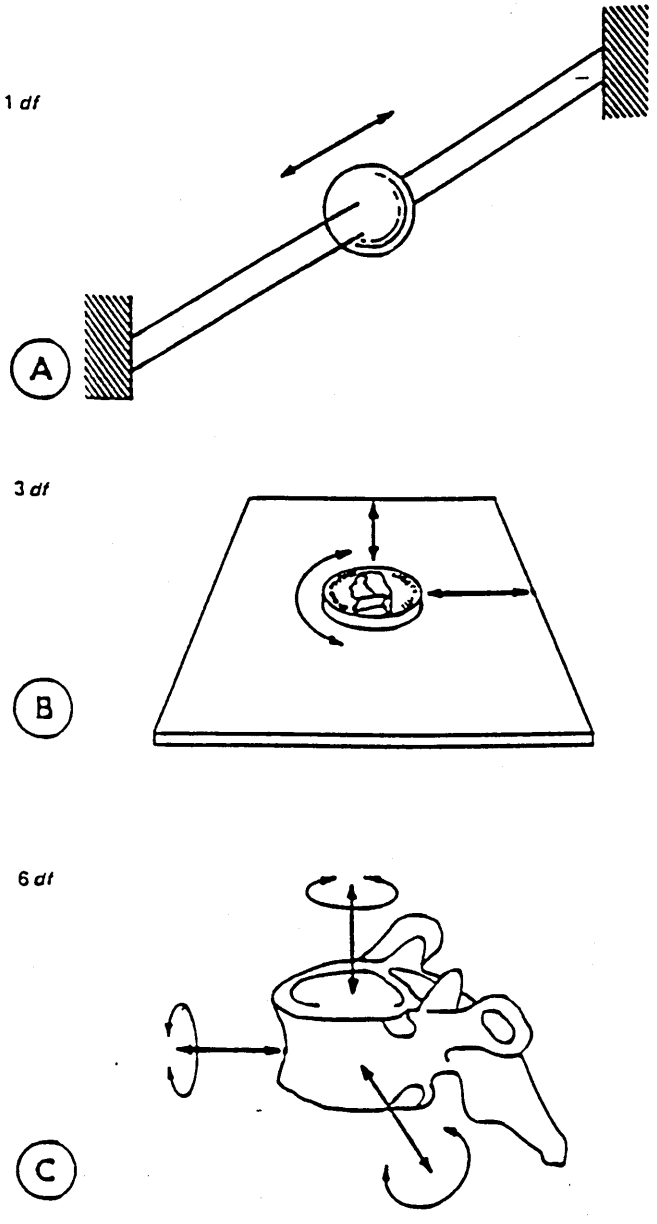


Figure 2.1: Concept of degrees of Freedom (df) involved in engineering analysis in kinematics shown diagramatically A. One degree of freedom B. Three degrees of freedom C. Six degrees of freedom possible for vertebrae (White and Panjabi, 1978).

Range of Motion: an indication of the two points at the extremes of the measurement range of translation and rotation of a vertebra for each of the six degrees of freedom. A range is expressed as 2 figures e.g. a range from 40 to 60 degrees.

Excursion: An indication of the change in joint angle possible at the joint and calculated by subtracting the lower range value from the upper range value. An excursion value is expressed as one figure e.g. an excursion of 20 degrees. These concepts are illustrated in figure 2.2.

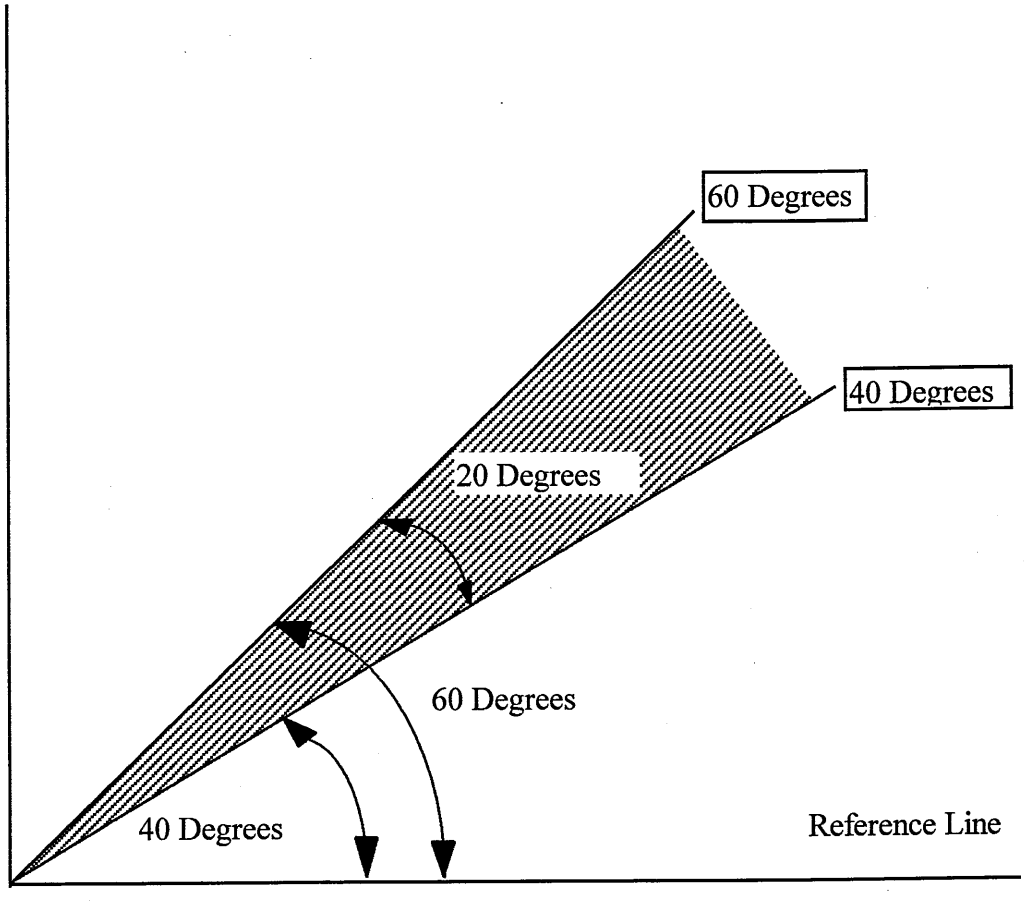


Figure 2.2: Schematic diagram showing the conceptual difference between "Range of Motion" and "Excursion" in relation to the motion of a human joint.

Coupling: Coupling is a term applied to motion in which rotation or translation of a rigid body about one axis is consistently associated with rotation about another axis or translation in a different direction of that same rigid body

Definition for a joint co-ordinate system

Winter (1979) stated that the complete kinematics of any body segment in a three-dimensional spatial system requires a number of variables. These include: position vectors, linear velocity and acceleration of the segment's centre of mass, angular orientation, angular velocity and angular acceleration of the segment.

In order to describe and measure any of these variables a co-ordinate system is required for reference. In the human spine the motion of one vertebra is often described relative to the subjacent vertebra using 3 orthogonal axes or a Cartesian Co-ordinate system (figure 2.4)

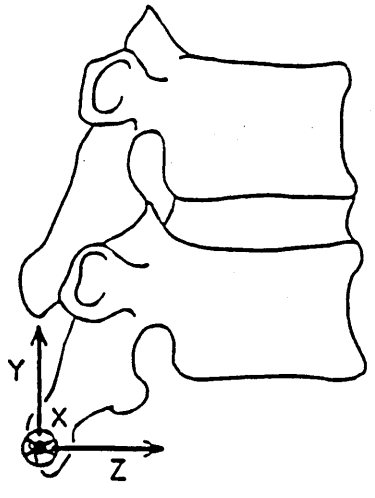


Figure 2.4: Motion segment with the reference point at the tip of the spinous process of the subjacent vertebra. The orthogonal system is presented in the Y, Z- plane . The X-axis is indicated by convention with the cross representing the base of the arrow. (White and Panjabi, 1978).

However a number of alternative co-ordinate systems exist. For example polar co-ordinates which use longitude, latitude and radius or helical co-ordinates which use radius pitch and length. The biomechanical community is currently exploring the scientific merit of these alternative forms. In both the clinical and biomechanical literature these forms remain relatively uncommon with most studies using a Cartesian co-ordinate system. In a Cartesian co-ordinate system the location of the object is given by three co-ordinates which represent the translation of the centre of mass along the three axes. The orientation is given by three angular rotations around the axes, which when applied in sequence transform the axes of the co-ordinate system to those used to define the moving object. This sequence of three angular rotations is known as an Euler Sequence and the angles as Euler angles. These angles are common in aviation and water transport where they are often called roll, pitch and yaw.

The sequence in which the rotations are performed is important in that application of the same Euler angles in different sequences results in different orientations i.e. 60 degrees flexion followed by 20 degrees sidebending and 55 degrees of axial rotation will result in a different final orientation than when applying 20 degrees sidebending followed by 55 degrees of axial rotation and 60 degrees of flexion. A further illustration of the problems associated with the 3 dimensional measure of joint angles is given by Codman's paradox. From the anatomical position abduct the arm 90 degrees then horizontally adduct the arm and extend the arm and it ends up with an internal rotation.

In order to overcome this sequence problem the bioengineering literature often uses a Cartesian co-ordinate system but describes orientation as "direction cosines", which unambiguously determine dimensional orientation of the object. However this method is difficult to use in a clinical environment or to explain to non-mathematically trained clinicians.

Woltring (1994) pointed out that, in clinical circles there is a " desire to use a quantitative measure for what the physician is used to observe with the naked eye" and hence he used a system based on Euler's theorem. An and Chao (1984) called this system a spherical joint model and it is nowadays commonly used for analysing anatomical joints.

This type of joint model allows three degrees of freedom for rotation; in other words, three angles are required in order to specify the relative position between the moving and fixed segments. It should be reiterated that for finite spatial rotation, the sequence of rotation is extremely important and must be specified for a unique description of joint motion when using the Eulerian method. To analyse joint movement it is usual to use two sets of axes, one fixed to the proximal segment and the other fixed to the distal segment. The rotation which occurs. between them can be expressed by a rotational matrix in terms of Eulerian angles (Φ,Ψ,ϕ). The Eulerian angles can be calculated based on the known orientation of the two axes sets attached to the segments.

This method can be applied in three ways to the spine (Stokes, 1994):

1. A local axis system which deals with the biomechanics of individual vertebrae.
2. An axis system which defines a spinal axis system for the entire trunk.
3. A regional axis system which is used when spinal deformities are considered and which covers a section of the spine involving a number of movement segments.

Fielding (1959) recommended the use of a right-handed orthogonal (Cartesian) co-ordinate system. A modified version of this was proposed by Stokes (1994) which was based on ISO 2631 (VDI 2057) and uses a right-hand convention in which X is forward, Y left and Z up. In this system there is no possibility of using different systems for the two sides of the body. This is different from the International Society of Biomechanics (ISB) recommendation (Wu and Cavanagh, 1995) which has X forward, Y up and Z right. However, the ISO system

could readily be adapted to the ISB system, using, altered conventions for axis names and directions.

The measurement instrument used in this study (3 Space Isotrak) uses the system of terminology proposed by Stokes (1994) as it recognises the 3 dimensional nature of lumbar spinal pathology and is intended to rationalise communication in both research and clinical practice.

2.2.2 Defining lumbar spinal kinematics:

Lumbar movements are described clinically in terms of flexion-extension, lateral bending and axial rotations. These movements are referenced to the three body planes (sagital, frontal and transverse). While the observed motion is conveniently considered as a single axis or hinge type motion, it can nevertheless be shown that these apparently simple motions are in fact quite complex (White and Panjabi, 1990).

Rigid body motion is described in biomechanics in terms of rotations and translations. Chao, (1980) states that these motions should be referenced to a central co-ordinate system represented by three orthogonal axes labelled X, Y and Z. In order to analyse true lumbar function, lumbar movement must be looked at as a multiaxial motion independent of movements occurring at related areas.

Biomechanically, joint mobility is dependent on the number of independent motions available. These independent motions are described as Degrees of Freedom (Panjabi, 1973). The lumbar spine has 6 degrees of freedom (White and Panjabi, 1978). The 3 rotations and 3 translations represent 6 independent motions. Using this format the classic spinal rotations of flexion-extension, lateral bending to the left and right and axial rotation to the left and

right can now be redescribed as 3 independent rotations, where flexion is a positive rotation about the Y-axis, extension a negative rotation around the Y-axis, lateral bending to the right a positive rotation around the X-axis and lateral bending to the left a negative rotation about the X-axis, axial rotation to the right a positive rotation about the Z-axis and axial rotation to the left a negative rotation about the Z-axis.

Provided these three rotations can be monitored alongside the 3 co-ordinates describing the centre of mass of the object over a period of time, then it is possible to fully describe the motion of that object in 3 dimensional space.

2.3 Measurement of Human Spinal Kinematics

The lumbar spine is a fascinating structure. The quantitative characteristics of the spine, however, are difficult to measure due primarily to its inaccessibility and the three dimensional nature of its movement pattern. Hence the evaluation of lumbar spinal motion has challenged researchers for years.

Since the first study on lumbar spine movement was published by Weber and Weber in 1836 many, both orthodox and heterodox, medical practitioners have investigated the kinematics of spinal movement in vitro (Hirsch, 1955; Loeble, 1967; Farfan et al 1970; Twomey, 1979; Yamamoto et al, 1989). In vitro study has the advantage that the motions can be directly and precisely measured and correlated with pathologic changes determined by subsequent dissection or histology studies. However, they have the disadvantage that because of post-mortem changes the measurements obtained may not accurately reflect the mobility in living subjects (Bogduk and Twomey, 1987). Moreover, Johnstone et al (1992) revealed important differences in mechanical behaviour of the spine in vivo and in vitro when they compared the fluid content of the human intervertebral discs removed at surgery and those taken post-mortem.

Therefore, the kinematics of interest is that of the living spine (White and Panjabi, 1978). However, the experimental techniques needed for precise, no-risk, in vivo clinical measurements are not yet fully developed.

In light of this and since this thesis is primarily concerned with kinematics of the living spine a specific review of in vitro measurements has been omitted. Nevertheless further references to in vitro studies are made throughout the thesis where they are considered to contribute to the understanding of the in vivo situation.

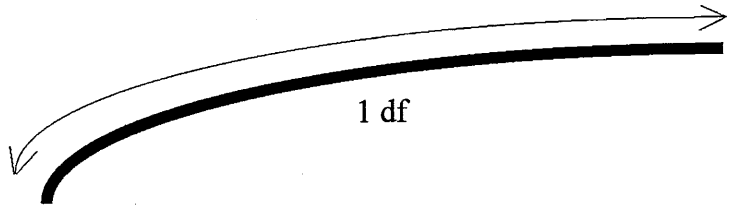
Taylor and Twomey (1980) reported on a classification system in which the different recording systems are classified on "how "the data were gathered without taking into account "what" kind of data the system gathers i.e. without looking at the level of sophistication of the data.

Taylor & Twomey (1980) reported the literature using 5 categories

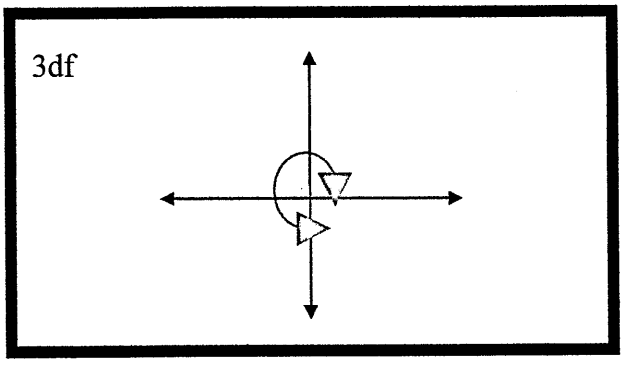
1. Direct measurement in living subjects.
2. Radiographic measurements
3. Cadaveric studies
4. Photographic techniques
5. Mathematical models

However of more relevance to the researcher and clinician is the "type" of data produced by these different methods. Therefore, a more appropriate classification system was proposed by Pearcy in 1986. This author suggested that the contemporary techniques used for measurement of lumbar spine motion could broadly be looked at in terms of the level of sophistication of data, starting with methods that give one-dimensional measures leading to those that give three-dimensional information.

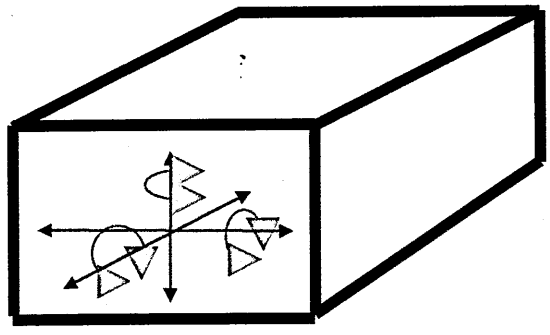
One dimensional techniques yields data with 1 degree of freedom and measure distances along a single fixed line. One df is then the distance along that line.



Two dimensional techniques measure data in a plane and consequently yields 3 df i.e. a translatory movement along the X-and Y-axis and a rotation in the plane of movement, in this case around the Z-axis



Three dimensional techniques measure data in a volume and have 6 degrees of freedom i.e. 3 translations and 3 rotations.



This review is therefore structured in sections which give the one, two and finally three dimensional measures of human spinal motion. The review will present an overview of the most common measurement techniques used in the clinic and the clinical research environment.

Techniques which are difficult to implement in clinical practice or whose use has been limited to research laboratories have been omitted.

2.3.1 One dimensional measures:

Skin-distraction technique for measuring flexion: This technique was described by Schöber in 1937 (Schöber-test) and modified by Macrae and Wright in 1969. The superior edge of the sacrum is palpated between the two " Dimples of Venus", over the posterior superior iliac spines (PSIS) and the skin marked. With the subject standing upright, points 100 mm above and 50 mm below this point are marked on the skin. The subject is then asked to bend forward as far as possible and the separation between the second two marks recorded. The use of the technique for measuring backward bending is not very satisfactorily because, although a measurement of the approximation of the skin marks is possible, the skin usually

bunches up making identification of the length to be measured very inaccurate (Pearcy, 1986). Moll et al, (1972) used this technique for assessing lateral flexion by measuring the separation or approximation of skin marks on the lateral trunk (Moll's-test). However, one might question if these skin makers reflect the movement of the underlying spine in these tests?

Williams et al, (1993) further modified this technique by using a distance of 150 mm measured cranially from PSIS. The rationale for this was that a 15-cm distance superior to the line intersecting the line connecting the PSIS's gave a more accurate representation of the actual length of the lumbar spine (Van Adrichem and Van der Korst, 1973). In addition these authors eliminated the additional landmark 50 mm below this level as this point was difficult to accurately identify due to its location in the upper part of the natal cleft on most individuals.

Macrae and Wright (1969), Fitzgerald et al (1983) and Williams et al (1994) all reported high reliability scores with this method. In contrast, Reynolds (1975) reported a low reliability score with the same method. Rae et al (1984) were able to discriminate between patients with proven spinal pathology, mechanical low back pain and normal subjects. These authors recommended that this test should become the standard clinical technique for measuring lumbar spinal flexion and should be a routine part of the examination of a patient presenting to an orthopaedic clinic with LBP. However, this test does have the inherent problem of localising landmarks which may be difficult to locate depending on the subcutaneous fat thickness. Skin extensibility is age dependent, therefore taking skin mobility as an accurate reflection of the underlying movement of vertebrae could be erroneous. Furthermore to date no evidence has been provided as to whether the Schöber-test was valid in assessing lumbar flexion. Finally, the inability to record lateral bending or axial rotation will reduce the clinical usefulness of this test.

Finger-to-floor distance

Merritt et al (1986) described this technique in the following way "while standing barefoot, heels on the floor, feet at shoulder breadth and knees straight, subjects are asked to bend forward maximally as to touch their toes and to maintain this position for 15 seconds. The distance from the tip of the middle finger to the floor was measured with a tape measure and recorded to the nearest 1/2 cm.".

Although this technique is still the most common way of objectively measuring lumbar flexion (Newton and Waddell, 1991), several authors reported poor reliability scores for this test (Gill and Callaghan, 1996; Merritt et al, 1986). Similarly, Frost et al (1982) measured total RoM in trunk forward flexion and lateral flexion as the distance from the fingers to the floor, and they measured trunk rotation and extension as the change in distance between bony landmarks. Only the measurement of anterior flexion was reported to have acceptable reliability. Burdett et al (1986) concluded that this method could not be used to separate measurements of regional lumbar spinal or pelvic motion and hamstring extensibility. In addition because of differences in arm length among subjects it may not be appropriate for making comparisons among subjects. Furthermore the test can cause discomfort for patients, as maintaining the testing position required for accurate goniometric measurement takes at least 15 seconds. Tillotson and Burton (1991) found the finger-to-floor technique difficult to use, because it did not provide angular measures. Poor test validity, mainly because it does not discriminate between lumbar and hip mobility, will prevent this test from gaining further recognition among clinicians.

Plumb-line technique for measuring extension

This method was developed by Moll et al in 1972 and adapted by Merritt et al in 1986. With the subject in a hands-behind-the-head position, two marks are made on the skin in the frontal plane on the left side. The lower mark at the point where the frontal line crosses the iliac crest and the upper mark 20 cm cephalad. This upper mark provides more accurate measurement than that obtained with use of xiphisternal horizontal landmarks described by Moll et al (1972). The subject than holds hands in front of his trunk and feet are hooked behind a webbed belt at the ankle. From this position the subject bends backward maximally. A plumb line is dropped from the upper mark and the excursion of the plumb line is measured (in centimetre) at the level of the superior lateral pelvic crest. This value represents trunk extension

Merritt et al (1986) compared three easily performed objective techniques for determining trunk flexibility the common "finger-tip-to-floor"-test, the modified Schöber and Molls test i.e. the plumb line tests and the inclinometer method (see further), also called Loebl inclinometer method, and their inter-examiner and intra-examiner reproducibility. On 3 different days, each of the 25 normal subjects was tested by the same examiner (one of three). In 25 other subjects, the studies were performed by a different examiner (one of three) on each of 3 days. They reported the following mean coefficients of variation for inter-examiner and intra-examiner reproducibility of results, respectively: fingertip-to-floor, 83% and 76.4%; flexion (Schöber) 6.3% and 6.6%; right lateral flexion (Moll), 11.9% and 8.9%; left lateral flexion (Moll) , 10.2% and 9.5%; extension (Moll), 9.5% and 7.3%; lumbar flexion (Loeble), 9.6% and 13.4% and lumbar extension (Loeble), 65.4% and 50.7%.

The coefficient of variation (C.V.)

$$C.V.= 100.s/\overline{X}$$

gives an indication on how large the standard deviation is in relation to the mean value. It is an indication on how large the relative distribution is and is expressed as a percentage. i.e. the higher the percentage the more variation there is in the data around the mean. A low percentage score would indicate a good reproducibility and a high percentage would indicate a large variation in the data i.e. low reproducibility (Ejlertsson, 1984)

Merritt et al (1986) concluded that although the reproducibility of the "fingertip-to-floor" test and the Loeble extension test was poor, all other tests studied had good reproducibility. However no studies have been published on the validity of the plumb line technique and its clinical usefulness is questionable as limitations are apparent in respect of localising landmarks and the complexity of the measurement procedure. This technique is further limited if the subject is quite mobile as the bottom of the plumb line will hang away from the body. The large possibility of measurement error in this technique adds to its limited clinical usefulness.

Summary on one dimensional techniques

- Several one dimensional methods to measure lumbar range of movement exist. Although most of the existing methods seem to have acceptable reproducibility, no studies have been published on their respective validity.
- The one dimensional techniques are often unrepresentative of the actual movements of the spine and are of limited value in that the data they produce is thought to be representative of the range of motion but is not a specific measure of the true angular movement of the lumbar spine.
- The large possibility of measurement errors inherent in the use of these methods in addition to the limitation to one degrees of freedom measurements makes them of limited value in the clinical or research settings.

2.3.2 Two-dimensional measures

A two-dimensional measurement most often provides a rotation within a plane. It could also involve translation within the plane but when looking at mobility in the spine the concern is normally with the angular displacement of one body segment in relation to another (Pearcy, 1986).

(i) Inclinometer technique

The use of an inclinometer for measuring back movement was first described by Loebl in 1967. Loebl described the method for measuring four spinal segments using a commercially available engineer's inclinometer (a pendular goniometer). Because all angles are relative to the always-vertical gravity pendulum, motion can be measured across any segment by calculating the differences between angles measured while the back is in neutral, flexed, and extended positions.

To measure lumbar movements in flexion and extension the following procedure is used:

The spinous processes of L1 and S1 are palpated and the skin over these bony prominences marked. With the subject standing upright the inclinometer is held against the back of the subject, with the pointer vertical and free to move, over the two skin marks in turn. The difference between the inclinometer readings is recorded to give an angle of spinal curvature (lordosis). The subject then sits on a chair and flexes forward as far as possible. Inclinometer readings are repeated over the two skin marks. The subject then lies prone on a flat couch and maximally extends by propping himself or herself up on the elbows and the two readings are repeated. The difference between the three sets of readings give angles of flexion and extension.

Reliability data on the Loebl inclinometer are scant, a single report cited a mean coefficient of variation of 11.4% for the total range of spinal motion among nine normal subjects (Loebl, 1967). Merritt et al. (1986), in a comparative study (see under "plumb line

technique") reported intra and inter-examiner mean coefficients of variation respectively of 13.4% and 9.6% for flexion. These authors however reported poor reproducibility values for extension (50.7% and 65.4%). The value of this test lies primarily in its ability to measure spinal motion independently from hip motion.

Mayer et al (1984) introduced the " two-inclinometer technique". The first inclinometer is applied over the sacrum parallel to the spine. The second inclinometer is aligned in the sagittal plane, bridging the T12-L1 spinous process. Keeley et al, (1986) reported this instument to have a high degree of intra-and inter-tester reliability. Validity was confirmed by X-ray measurement (Mayer et al, 1985; Newton and Waddell, 1991). Although no construct validity has been established, the two inclinometer technique has been accepted as the preferred test in the revised American Medical Association (AMA) Guidelines to the Evaluation of Permanent Impairment (Engelberg, 1988).

The fallibility of this test, however, was demonstrated in a study by Lowery et al (1992). This study, using the same double inclinometer method as described above, tested 81 healthy volunteer subjects of various age groups and ethnic backgrounds. The RoM were then compared to the AMA guidelines. They found that the intra-tester reliability was not nearly as consistent as reported by Mayer (1984) and, more importantly, all of these normal subjects were noted to be rateable with some impairment based on the AMA-guidelines, ranging from 25 to 38% with the mean value of 11%.

These findings must question the use of this technique as the standard method of assessment for back mobility.

(ii) Spondylometer

This instrument designed for the measurement of spinal mobility in the sagittal plane was first described by Dunham in 1949. It consist of two brass rods, hinged in the middle and the end connected to a protractor pointer. The protractor is held against the sacrum and the end of the linkage is held against the vertebra prominence. Movement of the trunk results in a displacement of the linkage and angular reading on the protractor. Sturrock et al (1973) used this device to measure ankylosing spondylitis patients. They reported minimal inter- and intra observer variation. In contrast, Ohlen et al (1989) reported large intra-observer variations for flexion and extension values. These authors also reported that the device is not widely used in a clinical setting. A major disadvantage for this system is that it measures spinal mobility in the sagittal plane only.

(iii) Flexicurves

The flexicurve is a draughtsman's device that moulds the spinal contour and hence measures the shape of the back. The contour then has to be drawn on a sheet of paper and tangents drawn to obtain an angle (Burton, 1986). The method for the lumbar spine employs three specific spinal landmarks i.e. S2, L4 and Th12. Burton (1986) reported good validity and intra-tester reliability. In contrast Lovell et al (1989) indicated that the inter-tester reliability of the method was doubtful. Pearcy (1986) found this device to be rather cumbersome and analysis of the shape by drawing round the device on paper and examining tangents at fixed points laborious. These findings severely limit the suitability of this technique for use in a clinical environment. Although the sensitivity of the method to record alterations in regional lumbar posture, resulting from ergonomic improvements, has been reported (Burton, 1986) the question remains as to whether the flexicurve technique is sufficiently sensitive to reveal patterns of mobility in relation to low back trouble. The major limitation for this system lies

in the fact that it only can produce static angles and hence its inability to record dynamic, functional movements.

(iiii) Photography & Video-recording

The sagittal mobility of the back has been assessed by photographing subjects with external markers attached to the back (Troup et al 1968). Side views of the subjects were used so that angles between rods protruding from the attached markers could be measured. This technique allows the subjects to move relatively unencumbered and permits assessments of postures adopted during work procedures (Davies and Troup 1966).

The accuracy of the results obtained by photography will to a large degree depend on the alignment of the camera and subject. Gill et al (1987) used the photometric technique as the "standard" for measurement of lumbar motion instead of radiographs. However, because of difficulties in placing markers on the chestwall and the variability of positions of the pelvis, the repeatability of the lumbar spinal motion measurements was not found to be good. These authors concluded that in order to use this technique for detailed quantification of flexibility, more markers (i.e. more than 4) would be necessary along the lumbar spine to improve the reliability of the method. Furthermore, the difficulty of concealing the identity of the subjects raises ethical issues which limits its widespread clinical use. Also, the relatively high cost of photographs and the delay in obtaining the final print are other practical limitations attached to this method. However, these problems can to some extent be overcome using polaroid film and digital cameras.

(iiiii) Electro-mechanical devices

As far back as 1986 an electronic goniometer was described by Adams et al. The measures for sagittal flexion correlated well with radiographic measures of flexion. However, the attachment of goniometers to the back, to provide continuous data during movement, posed particular problems due to the flexibility of the spine in three dimensions.

Paquet et al, (1991) developed an electrogoniometer based on a potentiometer for the measurement of sagittal dorso-lumbar movements (Th8-S1). Because the potentiometer of the electrogoniometer measures angular changes indirectly from changes in the curvature of a flexible slat, a special individual calibration procedure was applied, and computation of the electrogoniometric angles representing the dorsolumbar movement was made by software. The length of the slat can be changed to adapt the electrogoniometer to different statures. High reliability scores were reported and validity measured by comparison with the angle values obtained by a two-inclinometer method were reported to be good. However, clear limitations were reported such as:

- The necessity of using a correction factor in order to provide individual calibration to take into account anthropometric features.
- Validity and reliability values were assessed for only sagittal dorsolumbar movements from the upright position to about 50 degrees of forward flexion.
- The selection of a flexible slat of appropriate length for the spinal segment to be measured. Due to the combination of straps and a physical connection between the potentiometers there will be inherent, non-linear effects, such as stick-slip and backlash problems.
- It's clinical applicability is limited because it provides information concerning the sagittal plane only.

A different design, based on a flexible shim, instrumented by strain gauges, was recently introduced by the Penny & Giles Company®, (Blackwood, Gwent, UK). Although this method had been used to provide objective information on the functional ability of hip replacement patients (Rowe et al, 1989) no studies were found reporting its use in LBP measurements. The flexible nature of this device means that it can be attached to the skin without the complicated linkages used in other electro-mechanical devices.

Also, before this device could be used in LBP measurements, specific transducers have to be developed. Further factors to consider with this device would be:

- The direct connection between the 2 endplates accommodates only 30 mm of telescopic extension which would not be sufficient to measure forward flexion of the lumbar spine.
- Due to the fragile design of the device (especially the wire connections), more vigorously executed movements will be difficult to measure.
- At present only a two dimensional version of the device is available which is limited to measuring angular motion. No three-dimensional version, which could measure all 3 angles exists.

(iiiiii) Measurements from single plane radiographs.

Although measurements from radiographs are not very useful for routine clinical use they are mentioned in this overview as they are often used as "gold standards" with which other measurements are compared.

There exists a plethora of studies which describe lumbar spinal movement from radiographs, albeit mostly from older datum (Gianturco, 1944, Elward, 1939; Allbrook, 1957; Pennal, 1972; Hayes et al, 1989). Using plane radiographs it is only possible to measure movements in that plane. To measure flexion and extension lateral views are required and for lateral bending anterior-posterior views are required. If there are movements out of plane, for example, if flexion or axial rotation occur simultaneously with lateral bending, then the

measurement from the radiographs will be erroneous, This may not matter in an abnormal movement that is measured specific to a pathology as has been claimed by Weitz, (1981). It should be borne in mind that the angles quoted are not necessarily true angles in that plane. The measurements from plane radiographs give us an excursion value. However, they do not indicate how the vertebrae moved from one position to another. Although serial radiographs can be taken to assess dynamic movement (Seligman et al, 1984) the application is limited due to the laborious nature of the analysis and the radiation dose. Cineradiography and cinegraphic techniques are now used to give moving pictures to illustrate instability. Accurate and comparable measurements from these two-dimensional radiographic techniques are only possible if the positioning of the subject and the X-ray equipment are carefully controlled so that the alignment of the subject with respect to the X-ray plate and X-ray source are reproducible (Pearcy, 1986).

Radiographic measurements, although often used as the "gold standard" are indeed prone to large errors if not properly taken. Difficulties with radiographic measurements include the clarity of the image (number and positions of chosen landmarks) and the process of tracing and superposition. The main disadvantages however, inherent to all X-ray photogrammetric techniques, is the radiation and the need to freeze motion in order to obtain at least two-good-quality images will always limit this technique to use in research laboratories.

Summary

Although two-dimensional measurement techniques provide the clinician with more accurate information on lumbar spinal movements than one dimensional techniques several important limitations still exist:

- The techniques allow the clinician to quantify excursions of motions in different planes but not simultaneously. Consequently no information on motion patterns could be gathered.
- Although most of these simple techniques are attributed acceptable reproducibility especially those providing measures of sagittal mobility, the data that they provide are limited in scope when compared to three-dimensional techniques.
- Although a wide variety of methods to measure lumbar range of movement exists no one method has been developed fully for routine clinical use.
- These techniques provide the clinician with an index of lumbar mobility but are unable to reflect the true dynamic nature of lumbar spinal motion. Moreover, pathological conditions may introduce out of plane movements which are impossible to quantify with these techniques. In view of this and as a consequence of the three dimensional nature of spinal movements the future would appear to lie with the three-dimensional measurement systems.

2.4 Three-dimensional techniques

2.4.1 Introduction

Vaughan (1995) stated that

> "Despite the fact that we live in a three-dimensional (3-D) world, nearly all published biomechanics research has concentrated on planar movement. Why is this? Until fairly recently we lacked the necessary technology to study 3-D phenomena in a routine manner. Furthermore, mechanical analysis of 3-D phenomena is not simply half again as difficult as 2-D analysis-it is an order of magnitude more challenging".

In the 1950's the advent of high-speed photography, together with the emerging possibilities of digital computation, opened up new horizons for study of normal human locomotion, joint replacement, amputee and gait, as well as sports biomechanics and investigations of trauma (Allard et al, 1995). More recently, the advent of real-time data acquisition has led to an explosion of possibilities in the field

As with one and two dimensional techniques this overview will be limited to non-invasive techniques which have a proven or potential clinical value.

2.4.2 Stereo-radiographic reconstruction

The term "stereo" encompasses all the X-ray techniques that provide three-dimensional information (Pearcy, 1986). The requirement is to produce two images of a subject in any one position from separate vantage points. In unipolar techniques this is archieved by two X-ray source positions with a single X-ray film plate. The X-ray film is changed between exposures so that two oblique radiographs of the subject, in each position, are obtained. Biplanar techniques uses two X-ray source positions and two filmplates, most commonly sited orthogonally (Stokes et al, 1981). The orthogonal biplanar method enables standard lateral and anterior-posterior radiographs to be taken and also gives the discrimination of all three-dimensions. Once stereo pairs of radiographs are obtained the analysis of movement relies on the ability to identify anatomical landmarks on each vertebra in the two views. This is the most inaccurate part of these techniques and several methods have been devised to reduce the errors introduced by manual identification of landmarks (Selvik, 1989). The complexity of the landmark identification and data entry procedure require a skilled operator making these techniques of research use only. The main drawback with stereo

radiograph techniques, even for research, is the X-ray dose involved, although, with the use of automatic exposure meters, fast screens and film, acceptable levels can be reached to enable studies of both normal and patient groups (Pearcy, 1985). This method, once again, only give ranges of movement and does not provide information on the pattern of movement and can only be used for static measurements.

Lysell (1969) and White (1969) described early applications of stereo-radiography to the measurement of spinal kinematic properties, including the "coupling" of motion that occurs in spinal motion segments specimens. Several investigations of subjects with low-back pain have been conducted using biplanar X-ray methods in an attempt to establish correlations between lumbar spinal motion and pain (Stokes et al., 1981; Pearcy, 1985; Stokes and Frymoyer, 1987;). These studies were complicated by the fact that subjects with LBP tend to have a reduced range of motion of a magnitude close to the precision of the measurement technique. Also, subjects must hold the spine in a selected position for the duration of the radiographic exposure. It is probable that a more continuous, more precise measurement of spinal motion would be more successful in providing information of diagnostic value. Digital radiography also called Cine radiography (which uses digital sensors in place of conventional photographic film) would overcome many of the above mentioned difficulties by allowing lower dose techniques and permitting more rapid analysis of the images. Automated image processing, permitting automatic recognition of landmarks, could also provide substantial benefits. This approach is being investigated in the field of angiography for measurement of motion of the heart (Smith and Quarendon, 1985). No studies, investigating the dynamic motion of the lumbar spine, were found in the literature.

Overall, stereo and biplanar X-ray techniques hold a special position in the study of 3-D human motion, which is currently dictated by the technology of image acquisition and analysis (Stokes, 1995). Despite the many drawbacks and limitations stereo-radiography

remains the "gold standard" for measuring Range of Motion (RoM) of the spine. Where validation studies have been carried out for one and two-dimensional techniques the RoM measured is compared to stereo-radiography. Also, newly developed 3-dimensional techniques are often tested for accuracy when compared to stereo radiography (Pearcy and Hindle, 1989; Adams and Dolan, 1986, Schuit et al, 1997). However the use of a potentially harmful X-ray beam to measure spinal motion will continue to limit the applications of this technique.

2.4.3 Acoustic sensors based goniometers

Acoustic sensor systems usually include an array of acoustic sources (e.g., spark gaps) and an array of at least three non-linear receivers (microphones), which define a body co-ordinate system (BCS). Acoustic waves are generated and transmitted by the sources, and are received by the microphones. Because the speed of sound is known, the system can calculate the location of the receiver relative to the sources. By fixing the sources within a laboratory co-ordinate system, the complete three-dimensional location of the receiver can be determined. When the spatial location of all the markers in the array is known, the position and orientation of the BCS can be calculated, thereby fully characterising the six degrees of freedom of the rigid body. Several kinematic studies have reported its use in joints such as the wrists (Andrew and Young, 1979), the ankle (Siegler et al, 1988), and the knee (Quinn and Mote, 1990) although no studies were found in the literature on the use of acoustic sensors to measure lumbar spinal function.

In a well controlled experimental setting Quinn and Mote (1990) reported errors smaller than 0.5 mm in translation and 0.5 degrees in rotation. These figures are comparable with the accuracy figures reported for electromagnetic devices and well within the error margins used in kinesiological studies. However, the soft tissue motion encountered in dynamic

studies, the relative size and orientation of the source and sensor array segments, needed to create a good signal-to-noise ratio, and the acoustic echoes, interference patterns, and sparking introduced by multiple acoustic source/sensor pairs make this approach difficult, at the present stage, to apply to dynamic motions studies of human subjects involving multiple body segments such as the lumbar spine. Further developments in the design of acoustic sensor systems may make it a viable alternative to other easy-to-use (and calibrate) systems.

2.4.4 Photogrammetric reconstruction (Opto-Electronic systems)

Opto-electronic systems analyse movement based on the measurement of the position of optical markers in three-dimensional space. This procedure requires attaching markers to the moving subject and then identifying the markers in the pictures produced by the cameras.

The image created by a camera represents a two-dimensional object. Therefore the challenge in using cameras to measure motion is to recreate the three-dimensional object that gave rise to the two-dimensional projection. This process is called photogrammetric reconstruction (Ladin, 1995). The extracting of the image co-ordinates from the film of the cameras is automated by electronic extraction of that information.

Two types of marker systems can be distinguished:

Active markers with Light Emitting Diodes (LED's) that emit infrared light and passive markers using light reflecting devices that reflect ambient or projected light.

The determination of the camera parameters requires a calibration procedure. This step is performed using a set of pre-calibrated markers, usually attached to known locations on a rigid frame. Each marker provides one set of two equations. The global co-ordinates of the markers are known, and the image co-ordinates are measured by the cameras. Because the equation is linear, a minimum of six markers, generating 12 independent equations, is

required to determine the camera parameters. In order to reduce the errors and provide a degree of redundancy to the process of parameter determination, more markers are often used. Once the calibration procedure has been completed for both cameras, the parameters are stored and the image co-ordinates can then be transformed into global co-ordinates for any marker. It is imperative that the position of the cameras and their spatial orientation be unchanged during the experiment. Any relocation or reorientation of the cameras requires recalibration (Allard et al, 1995).

Digital computers connected to television cameras were used to record the position of reflective markers, attached to the subject and illuminated by stroboscopes (Vicon®, Oxford Metrics Ltd, UK). Pearcy et al (1987a) used this system to record movement patterns of the lower back in 6 normal individuals. Such a system has also been used to examine back and pelvic movement during walking and there is obvious potential with these devices for assessing trunk movements (Thurston and Harris, 1983). However, Thurston (1982) reported that the lack of discrimination between closely spaced markers and the absolute accuracy of the three-dimensional co-ordinates produced, limit these techniques to movements where it is acceptable to have markers on long outriggers. Furthermore, Pearcy et al, (1987a) concluded that these opto-electronic systems are not ideal for detecting individual markers in space for the measurement of three-dimensional rotations because three markers in rigid conformation are required to define planes, leading to two main problems. First, the necessity for cumbersome mounting rigs which have to be attached to the subject. Second, to calculate the rotations of the planes it is necessary to measure small changes in relatively large dimensions. Thus for the spine these systems may be regarded as suitable for the measurement of two-dimensional movements occurring in three-dimensional space but not for three-dimensional movements (Pearcy et al, 1987a).

Finally, opto-electronic systems are sophisticated and expensive systems and they require skilled operation to obtain repeatable results. This, together with the time required for

markers to be attached to the subjects, the movements to be performed and the results analysed, makes their potential use difficult in a routine clinical setting (Pearcy et al, 1987a).

There is a dearth of 3D studies, using opto-electronic systems, in the analysis of LBP patients. This is in contrast to the abundance of studies published on gait analysis. Jayaraman et al (1994) used a computerised technique, employing a motion analysis system and a force plate to analyse 10 LBP-patients. They reported that the pattern of motion seen in lateral bending, rather than range of motion, was most affected in subjects with low back pain.

2.4.5 Potentiometer based angle measuring devices.

An accurate kinematic measurement of the completed joint rotation requires that the goniometer measure the full three degrees of freedom that characterise such a joint.

Three potentiometer-based goniometers are described in the literature:

(i) Standard Link based systems

The first multi-degree-of-freedom devices were described by Sommer and Miller (1981) and Lewis et al (1988). The first designs of goniometric systems that could accommodate more than a single degree of freedom were based on the parallelogram linkages to transmit perpendicular rotating axes to a monitoring potentiometer. Such a design could accommodate some degree of rotational and translational misalignment between the joint's instantaneous centre of rotation and that of the potentiometer, but still represent a measurement system that is sensitive to the attachment of the goniometer. More recent designs use a combination of single-axis potentiometers, interconnected by small, rigid links.

The errors obtained in such a goniometric system use less than 1 mm in translation and less than 1 degree in rotation, (Suntay et al, 1983) which are small and comparable with the errors obtained in electromagnetic devices which are described later in this thesis.

Ladin, (1995) pointed to some practical limitations that prevent such systems from gaining widespread acceptance in clinical studies:

- Specific transducers must be developed for different joints (e.g. goniometers for the lower limbs could not be used for the upper limbs, the back, or the neck).
- The goniometric system is cumbersome (and sometimes heavy) and has difficulty in accommodating different size individuals.
- There are inherent, non-linear effects, such as stick-slip and backlash problems, in the mechanical linkage system.
- Relatively little is known on the practicability of the system for measuring spinal back function.

(ii) The OSI CA-6000 Spine Motion Analyzer® (OSI SMA) (Orthopedic systems, Inc. California, USA)

The OSI SMA consists of a mechanical linkage that contains six potentiometers and was especially designed to measure spinal motion. The potentiometers permit recording of motion of the cervical, thoracic and lumbar spine in all three cardinal planes simultaneously. Schuit et al (1997) investigated the level of agreement between angular measures of lumbar spinal motion recorded by the OSI 6000 and measures obtained from X-rays of subjects without lumbar symptoms. In addition, they investigated the inter-tester reliability of measures of lumbar spinal range of motion using the OSI SMA on individuals with lumbar symptoms. Within the limitation of their small sample size study, measures obtained form the OSI CA 6000 were similar to those obtained from X-rays in subjects without lumbar

symptoms for the motions of flexion, extension, right side bending and left side bending. Measures of active lumbar range of motion obtained with the OSI SMA in subjects without lumbar symptoms and in subjects with lumbar symptoms were consistent over repeated trials. These authors concluded that the device was a valid and reliable apparatus for the clinical measurement of motion of the lumbar spine in the sagittal and frontal planes, and a reliable apparatus for the clinical measurement of lumbar rotation. The results of this study are similar to the values reported by Troke et al (1996) also on normal subjects. McGregor et al (1995) found the device to be "excellent and accurate" in all three movement directions when tested against a workshop mill measurement system and Dvorak et al (1992) found the device to be accurate within 0.1 degree in flexion-extension, but not for axial rotation. A recent study by Christensen (1999) reported very high precision values (± 0.1 degree for 4 different angles in 6 different movements). However, when tested for accuracy by comparing the electrogoniometer to the values obtained by 2 kinds of manual protractors substantial disagreement was found and consequently the accuracy of the device was reported to be less than acceptable.

In conclusion, the direct physical connection between the potentiometers limits its applicability to static, gross movements excluding dynamic functional movements.

(iii) The Lumbar Motion Monitor® (LMM, Chattex Corp, USA)

The LMM is an exoskeleton with three wires running the length of the device. Attached to these wires are three potentiometers one for each direction of movement, tension on which causes voltage changes which are related to angular position. No paper was found in the literature which explains the design, construction and conceptual basis of this device. Marras et al (1992) investigated the accuracy of the device and also the reproducibility of the values for all RoM's, velocities and accelerations. Their results demonstrated higher reproducibility values than found in a more recent study by Gill and Gallaghan (1996).

A potential source of error is that the LMM is designed to measure the thoraco-lumbar motion from approximately T7 to S2 but has a fixed length. Therefore individual variations in scapular position and spine length will cause a different number of spinal segments to be measured. Validity could thus be improved. In addition the LMM is also limited by the requirement for direct connections across the region. Despite this potential source of error, the LMM was found to have acceptable reproducibility, especially with RoM and velocity measures.

The desire to measure joint rotations directly, while eliminating the mechanical-link coupling introduced by any of these linkage based goniometers, has led to the development of electro-magnetic measuring devices.

2.4.6 Electro-magnetic kinematic measurement devices

These devices are based on two small units, one serving as the source and the other serving as the sensor, both connected by cable to a system electronics unit. Both the source and the sensor contain three sets of orthogonal coils. By exciting each loop (coil) in the source with an identical low-frequency electro-magnetic signal, a pattern is generated in the source (Krieg, 1984). This yields a set of three linearly independent vectors, which can be measured by the sensor. The signal picked up by the sensor contains enough information to discern the relative position and orientation of the sensor with respect to the source. The algorithm necessary to determine the kinematic variables is based on the linear small-angle rotation approximation of the trajectories traversed over a short period of time.

This "position and orientation measurement concept ", was patented in 1976 by Kuipers. The military industry used it in a number of helmet-mounted sights applications to measure the orientation of the helmet and consequently its wearer's line-of-sight.

Presently two sorts of devices are commercially available.

First, a device called Isotrak 3Space® developed by Polhemus Navigation, Colchester, VT, USA. A more recent variant of the Isotrak 3 Space, also developed by Polhemus Navigation is called the "3Space Fasttrak ". This device is basically the same as the older Isotrak 3 Space model but has the additional feature of having multiple sensors so that the motion of different joints can be recorded. However, multiple sensor use reduces the sampling frequency. Both of these devices are based on alternating current.

Allard et al (1995) indicated several factors to be considered when using these devices:

- Electromagnetic interference from metallic objects near the sensor can distort the output signal.
- The relatively slow sampling rate (60 Hz), limits the speed of joint rotation that can be accurately tracked.
- The small number of sensors (a maximum of four sensors and two sources) limits the number of joints that can be tracked.
- The range of angular motion of any rotational degree of freedom is limited to 180 degrees.

Secondly: a similar system called "Flock of Birds®" developed by Ascension Technology Corporation (Burlington, VT, USA) is based on pulsed DC (direct current) magnetic fields as opposed to alternating current in the previous mentioned devices. This device was recently tested for accuracy by Mildne et al (1996). The device was found to be insensitive to commonly used orthopaedic alloys and to have positional and rotational errors of less than 2% when utilised within its optimal operating range. This accuracy combined with its insensitivity to orthopaedic alloys make it a very versatile measuring device suitable for a use in musculoskeletal research investigations as well as in the clinic.

These electromagnetic devices would appear to have much to offer to the clinical measurement of 3D spinal kinematics in that they:

- have a high degree of reliability and validity
- are small in size
- have no direct physical link between the application sides
- are relatively cheap
- give angular and translational measures in real time
- allow the measurement of dynamic functional movements if properly secured

Clinical studies on lumbar spinal kinematics using electromagnetic goniometers

Buchalter et al (1986) used this electromagnetic technology to measure lumbar spinal motion, in real time, with six degrees of freedom. These authors reported no statistically significant evidence of organised coupling in the lumbar spine in healthy subjects. However a weak inverse relationship between the subject's age and range of motion was found. They also recommended the 3 Space system for continued use in the area of spinal motion research. An et al (1988) applied the 3Space Isotrak to a series of rigorous reliability and validity tests and found it to be "quite accurate and easy to use". Consequently these authors recommended the use of the device in biomechanical analysis of human movement. Pearcy and Hindle (1989) piloted the 3 Space Isotrak device for clinical measurements. The ability of the device to effectively determine the patterns of movement rather than just the position of the spine at the extremes of the motion was described as the major advantage over other 3 dimensional measuring devices. Moreover, Hindle et al (1990) developed an attachment system for the device as well as a normative database for lumbar movements. These authors were able to discriminate LBP-patients from non-LBP-patients on the basis of movement patterns. However, it is questionable whether this attachment system

adequately dealt with errors caused by the underlying spinous processes. Russell et al (1993) further extended on Hindle's study by including five age categories in his database. Strongly coupled movements i.e. lateral bend and axial rotation, flexion and lateral bend and flexion and axial rotation were reported. In addition, excursion values were seen to be affected by both the age and sex of the subjects. McGill and Kippers (1994) used electro-myography signals from in the back-extensors to investigate flexion-relaxation phenomena in normal subjects.These authors used the 3 Space Isotrak device in combination with electro-myography to accurately record position and rotation in three dimensions. Hancock (1995) reported on the potential of the Isotrak 3 Space as a physiotherapy measurement tool. She concluded that, due to discrepancies in locating anatomical landmarks and subsequent inaccurate application of the transducers, its clinical use would be restricted. In contrast Mulvein and Jull (1995), successfully used the 3 Space Fasttrak system to investigate the effects of lumbar lateral shift movements techniques in a physiotherapy clinic and Nelson et al (1995) used the Isotrak 3 Space to measure differential lumbar and pelvic motion during trunk flexion and extension. Pearson and Walmsley (1995) expanded the use of the device to the cervical spine and reported kinematic data on neck retraction and neck posture in asymptomatic subjects. Willems et al (1996), using the 3Space Fastrak system, established preliminary data on three-dimensional thoracic spine kinematics. The system could readily determine patterns of coupled motion in the thoracic spine. Maffey-Ward et al (1996) also using the 3Space Fasttrak, evaluated a clinical test to detect kinaesthetic deficits in lumbar spine patients. Ordway et al (1997) measured cervical flexion, extension and protrusion in a comparative study with lateral radiographs. They concluded that cervical flexion and extension could not occur in isolation from upper thoracic motion. Steffen et al (1997) validated a direct method for three-dimensional, in vivo, spinal kinematic measurements where they the used indwelling Kirschner wires attached to a 3Space Fasttrak system.

This study indicated that the 3Space Fastrak had the ability to dynamically record lumbar segmental motion. A measurement error comparable with stereo radiographic methods was reported. Recently, Burnett et al (1998) reported the first recording of a functional activity when they investigated lumbar kinematics during fast bowling movements in cricketers. Finally, Gatton and Pearcy (1999), using the "Flock of Birds", reported on the kinematics and movement sequencing during forward flexion of the lumbar spine.

2.5 Summary and conclusions

Movement of the lumbar spine can quantitatively be described by using kinesiological measurements.

Although most clinicians will only perform a subjective assessment of a patient's back movement by "eyeballing", the interest in objective, easy to use clinical measurement techniques is growing. The need to objectively quantify functional, dynamic movements in a clinical setting has been identified by clinicians as a priority in order to report treatment outcomes and progress related to disability scores reported by low back pain patients.

Contemporarily used, direct and in vivo, measurement techniques for lumbar spinal motion could be described in terms of their sophistication and their validity in the clinic.

Some of the one and two dimensional techniques have reasonably good reliability but lack validity. In addition, their inability to measure the 3 dimensional motion characteristics of the lumbar spine limits the information which the clinician could gain from their use.

Several three-dimensional measuring devices are available today, which could record spinal motion. Electromagnetic goniometers provide the clinician with a measurement tool which can give this information reliably and accurately in a clinical environment. They are relatively inexpensive, have been shown to be robust and do not require a physical connection between the regions of the spine under investigation.
They would appear therefore, to be suitable to investigate spinal kinematics in a clinical environment.

3. Orthopaedic manipulative therapy as a treatment intervention in low back pain.

3.1 Introduction

The use of the human hand as a method of relieving pain and reducing human suffering is probably the oldest remedy known to man. Touching, massaging and manipulating areas that are painful, tense or tight are activities used in every household and much of the animal kingdom (Haldeman, 1994).

Historically, when a patient has had a limited range of movement, the therapeutic approach has been to stretch the region with passive stretching techniques. However, over the past 30 years, therapists have identified and learnt techniques that deal more directly with stretching the source of the limitation, and thus managing dysfunction in an improved manner and so producing less trauma. Orthopaedic Manipulative Therapy (OMT) encompasses joint mobilisation and manipulation techniques designed to safely stretch structures and to restore a full range of movement combined with a reduction in pain in both peripheral and spinal joints (Kisner & Colby, 1990).

Manipulation and mobilisation techniques are currently an area of great interest for many different groups of medical professionals. Numerous seminars, books and videotapes are being used by health care professionals to teach the art of manipulative therapy (Harris, 1993).

Within the physiotherapy profession, OMT has been developed as a specialisation, evidenced by the formation of a special interest group in Orthopaedic Manual Therapy and the abundance of postgraduate course offered to physiotherapists. Although basic mobilisation skills form an integral part of the undergraduate curriculum in physiotherapy in

the U.K., most physiotherapists obtain more specialised instruction in OMT primarily by attending postgraduate courses (Evans and Richards, 1996).

Orthopaedic Manipulative Therapy techniques can be divided into two types: manipulations and mobilisations (Kisner & Colby, 1990) . The history of manipulations, which are defined as high velocity, low amplitude thrusts, as a treatment modality is extensive and has been reviewed by a number of authors in detail (Schiotz and Cyriax, 1975; Gibbons, 1980 and Harris, 1993). Their introduction into mainline medical practice is often attributed to James Mennel and Edgard Cyriax both of whom were followed by their sons John Mennel and James Cyriax who became advocates, authors and teachers of manipulations.

The use of high velocity, low amplitude thrusts for the treatment of low back pain has been investigated extensively and there is a growing body of scientific evidence substantiating their role in the treatment of acute low back pain (Koes, 1991; Shekelle, 1992; Anderson et al, 1992; Clinical Standards Advisory Group, 1994).

An enquiry to most of the physiotherapy schools in the U.K. could not reveal any undergraduate level courses where high velocity thrusts are taught. However, a limited number of physiotherapists learn these techniques through postgraduate courses (Evans and Richards, 1996). Therefore, the use of these high velocity techniques in the treatment of low back pain by physiotherapists is limited. In contrast, the use of mobilisations, which are defined as low velocity, non-thrust techniques, is widely taught at undergraduate level and hence these are the prevailing manipulative techniques used by U.K.-physiotherapists in the treatment of LBP (Evans and Richards, 1996).

3.2 Manipulation and Mobilisation: Definition & Types

Determining whether manipulation and mobilisation are effective tools for helping patients with back pain requires an understanding of the terminology used by practitioners of these techniques and the establishment of controlled, properly designed studies (Nyberg, 1993). It is incumbent on the scientific community to investigate, with a testable hypothesis, reliable methods and clear language, the clinical observations made by manipulative physicians and therapists. However, without the identification of terminology that is common to all involved in manipulative care, the ability to effectively communicate is impaired and research efforts to establish validity are hindered (Hadler et al, 1987). Furthermore, researchers and physicians who do not receive the theory, terminology and practical skills related to OMT during the course of an academic programme are inclined to have difficulty in accepting the therapeutic value of manipulation and mobilisation (Parker et al, 1978).

3.2.1 Definitions

Dorland's Medical Dictionary (1974) defines manipulation as

> "a skilled, therapeutic use of a passive movement designed to restore motion. Passive movement is further defined as motion not under voluntary control, but occurring in response to an external or outside force."

The words manipulation and mobilisation are given different meanings among health practitioners and lay people. However, different terminologies are in use, even within the same profession. For example, to some, manipulation is the use of a vigorous high-speed manual manoeuvre which repositions displaced bones into places and results often in a pop or crack (Cyriax, 1982). To others, manipulation may mean a gentle, refined motion which increases joint motion or soft tissue extensibility (Kaltenborn, 1993). Maitland (1986) uses the word "manipulation" in two ways. Firstly, as a general term to cover any form of

passive movement technique applied to a structure in order to treat a musculo-skeletal disorder. In this definition "manipulation" covers all forms of passive movement including low velocity mobilisation and high velocity manipulation. Secondly "manipulation" is used to describe a subset of techniques which he defines as

> " a technique at a speed such that it has taken place before the person on whom it is performed is able to prevent it".

Maitland goes on to say that such techniques are

> "often gentle, always small in range, and rarely forceful".

Mobilisations are not mentioned under this second definition of manipulation. Mobilisations are separately defined as

> "a passive movement performed in such a manner (particularly in relation to the speed of the movement) that it is, at all times, within the ability of the patient to prevent the movement if he so chooses."

This ambiguity and lack of clarity in the definitions of manipulation and mobilisation results in communication problems which ultimately lead to misconceptions.

Nyberg (1993) and Haldeman (1994) described the different kinds and types of manipulations and mobilisations currently in use. These authors categorise manipulations and mobilisations as two distinctively different treatment techniques which are performed at different positions and ranges of motion in a joint as illustrated in figure 3.1.

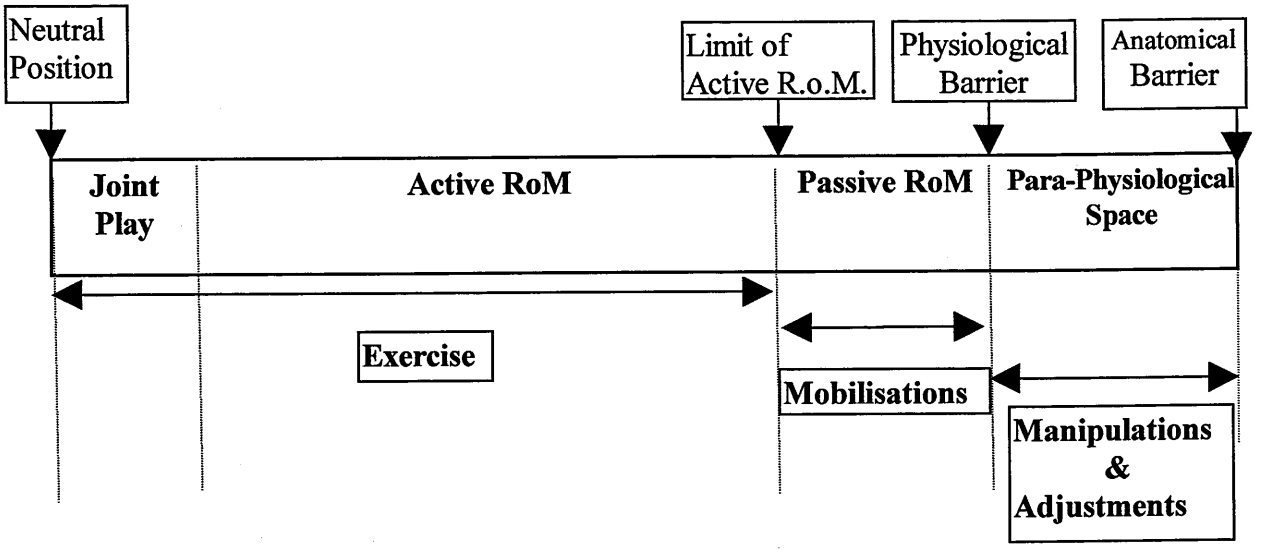


Figure 3.1 The presumed barriers to motion in a joint and the position or range of motion where the various forms of manual therapy are performed (after Haldeman, 1994).

Nyberg (1993) describes *Joint manipulation* as:

> "involves the use of high-velocity, low amplitude movements".

Joint manipulation using a high-velocity, low amplitude movement is also sometimes referred to as *thrust manipulation* (Nyberg, 1993). In osteopathic manual medicine the term *mobilisation with impulse* has been utilised as well (Kappler, 1981). Haldeman (1994) further describes manipulations

> "as thrusting techniques which force the joint beyond the physiological barrier of range of motion, through the para-physiological space to the anatomical limits of motion ".(figure 3.1).

This author also uses the terminology "adjustment techniques" as synonymous for manipulations. However, this term is predominantly used in the chiropractic literature (Haldeman, 1994).

Joint manipulation was not the subject of this investigation and these techniques were not used during this clinical trial, consequently this review will not elaborate further on these techniques. However the above definitions are required in order to distinguish manipulation from mobilisation as these terms are often used interchangeably.

Joint mobilisation: Mobilisation includes those manual procedures which attempt to increase the range of motion beyond the limit of active RoM, (where exercises are performed) and into the passive range of motion reaching the physiological barrier of motion (figure 3.1) (Haldeman, 1994). Mobilisation differs from manipulations in that it involves slower rates of force application compared to thrust techniques. In osteopathy, joint manipulation performed without "impulse" is referred to as mobilisation or *articulatory procedure* (Greenman, 1989). Forces used in joint mobilisation may vary from gentle to vigorous. Although huge variations exist in the forces used by different practitioners (Harms, 1997), they are always applied slowly as opposed to thrust or high-velocity manipulation. Since the force utilised is slowly applied, controlled, begins gently and gradually increases, the patient can report the effect during the force application. Moreover, the instantaneous feedback mechanism provides a sense of security for the patient and helps to increase the safety feature of mobilisation (Nyberg & Basmajian, 1993). In mobilisation three types of force application can be used: graded oscillation, progressive loading and sustained loading.

- Graded oscillations: is a form of cyclic loading whereby alternate pressure, on and off, is delivered to different parts of the available range (Maitland, 1986). The system designed by Maitland (1986) is the most prevalent in the U.K. and is taught as part of most of the U.K. undergraduate physiotherapy curricula. It uses a grading system from 1-5 to indicate the pressure exerted on the lumbar spine where grade 1 is the lowest pressure and grade 5 the highest pressure.

Although this grading system is widely used by teachers, clinicians and researchers alike no evidence was found in the scientific literature as to an acceptable inter & intra-rater reliability for the use of these grades. Consequently their value in the clinic and as a communication tool between clinicians and researchers remains questionable.

- Progressive loading mobilisation involves a successive series of short amplitude, "spring type" forces (Paris, 1990). The force is imparted at progressive increments of the range and is defined on a 1 to 4 scale as in graded oscillations. The force used with progressive load mobilisations is transmitted at different ranges, however the amplitude of each force is the same. Progressive loading requires skill in consistent reproduction of short amplitude, "spring" forces at different range increments. No scientific evidence exists at present on the consistency of force delivery in this type of mobilisations.
- Sustained loading is a continuous, uninterrupted force which may remain the same intensity, gradually increase or decrease depending on the patient reaction. If motion is being restored during a sustained loading, the therapist maintains the same loading force. If proper motion is not being facilitated, the therapist slowly and gradually increases or decreases the load applied until the desired motion develops.

As the kinetics of mobilisations are not the subject of this study an in depth overview of the different grading systems used to describe the oscillations has been omitted. Suitable definitions can be found in Maitland, (1984) or Kaltenborn, (1993).

3.2.2 Spinal Hypomobility and Back Pain

There is controversy in the literature as to whether limited spinal motion is a feature of low back pain or not. Million et al (1982) provided evidence for improvement in spinal function being related to the range of spinal motion but spinal motion correlated poorly with the patient's problems. Battie et al (1990) investigated 3020 employees of the Boeing Aircraft Corporation in a prospective study over 3 years. Sagittal and lateral flexibility were measured using a modified Schöber test, lateral bending test and a sit-and-reach test. These flexibility measures were not associated with risk of future back pain nor were any trends towards increased risk of LBP present. Therefore, the premise that spinal inflexibility is predictive of back pain may not be substantiated, at least not in an industrial setting and with the used flexibility measure. However, the measures of spinal motion used were not of a 3 dimensional nature and consequently did not assess spinal function comprehensively. Further work, using 3D assessment tools is therefore required to allow an association to be detected.

Although spinal flexibility measures may not be predictive for low back pain, an association between previous or current low back pain and spinal range of motion does exist (as discussed in chapter 1, recurrence rate). Noteworthy for clinicians is the fact that the limitations in spinal motion in LBP are not always to be found in spinal flexion and extension (Burton et al, 1989). Further evidence for this was provided by Sward et al (1990) who reported significant correlations between spinal motion restrictions in lateral bending and axial rotation and the degree of low back trouble in top Swedish athletes with LBP. Million et al (1982) also found positive correlations between LB problems and restrictions in lateral bending and axial rotation in a study on 151 men aged 54-63 years.

Furthermore, Troup et al (1987) reported a more marked decrease in range of extension than flexion in individuals reporting with LBP.

Despite evidence that spinal motions other than flexion may be limited by LBP, most clinical examinations of the spine tend to concentrate on lumbar flexion. Also, due to the three-dimensional nature of a restriction in the lumbar spine the value of exercise programme for LBP which only promote flexion or extension is questionable.

In view of the above, the use of simultaneous multi-plane motion measurements and treatments of the spine in low back pain patients would appear to be indicated.

3.3 The treatment rationale for using mobilisation techniques

An abundance of publications on the rationale of mobilisations and manipulations and hypotheses regarding their clinical effectiveness can be found in the medical literature. However, most of the hypotheses lack scientific evidence and much of the published research is flawed by poor experimental design and sub-optimal outcome measures. The following section presents a critical review of the available literature related to the treatment rationale for spinal mobilisation.

This review is focused on "low velocity" mobilisation techniques which are the subject of the present investigation. Studies which were purely concerned with manipulations (high velocity techniques) have been purposely omitted. However, in some studies a clear distinction between mobilisation and manipulation techniques could not be made. Consequently these studies have been included in the review.

3.3.1 Mechanical influences on tissue

(i) Mechanical Influences on Connective Tissue Extensibility

Several investigators have studied the deleterious effects on tendons and ligaments of prolonged immobilisation (Frank et al, 1984; Woo et al, 1985; Salter, 1989).

Histological studies demonstrated 3 main effects of immobilisation:

- A loss of the normal lubricating mechanism between collagen fibres due to decreased numbers of glycosaminoglycan molecules (GAG's) (Salter, 1989; Woo et al, 1975).
- The approximation and stationary attitude of collagen fibres leads to an increased number of adhesions (Akeson et al, 1977).
- The formation of an abnormal random haystack pattern and arrangement of new collagen fibrils (Woo et al, 1985).

The repetitive, low stress and small amplitude movements of mobilisation have been recommended as an efficient way to restore the extensibility of the joint capsule and ligaments as well as the myofascial tissues around the joint (Twomey and Taylor, 1995).

Woo et al (1975) demonstrated that a critical fluid barrier must be maintained between collagen fibres to allow realignment in the direction of the imposed stress or movement. GAG synthesis is stimulated by movement, thereby restoring lubrication efficiently and normal three-dimensional spatial patterns in the matrix.

Mobilisation techniques are usually performed in a non-weight bearing position, allowing good joint lubrication. In this way, its effects on the joints and associated tissues are similar to those of exercises (Twomey and Taylor, 1995).

Rupture of the abnormal cross-links and adhesions which form between fibres is another possible way in which spinal mobilisation and manipulation may work (Nyberg and Basmajian, 1993).

In conclusion, early mobilisation was found to promote cellular activity at the repair site with increased collagen content, improved fibre alignment and decreased scar adherence to surrounding tissues. In addition, the strength and stiffness of the early mobilised tissues were also significantly higher than those that were immobilised. Thus it is believed that passive movements such as those produced during mobilisation treatment are essential in stimulating healing and preventing joint contracture after mobilisation.

(ii) Mechanical influences on articular cartilage

Intra-articular effects of prolonged immobilisation of joints have been studied extensively in rats, rabbits and monkeys (Salter and Field, 1960; Trias, 1961; Thaxter et al, 1965). A consistent finding in immobilised joints is the progressive proliferation of fibro-fatty connective tissue into the joint cavity. Pressure necrosis of articular cartilage probably results from the restriction of synovial fluid from reaching the contact surfaces as well as the impedance of nutritive fluid diffusion within the intercellular areas of the cartilage (Salter and Field, 1960). The degree of stiffness appears to be proportional to the severity of articular degeneration particularly with respect to the presence of fibro-fatty and adhesion (Enneking and Horowitz, 1972). Furthermore, DiPalma et al, (1966) found that early motion activity and weight bearing have been found to enhance repair of full- thickness cartilage defects

Salter et al (1980) recommended the use of continuous passive motion to joints with full-thickness articular cartilage defects. This accelerates repair and produces tissue which resembles normal hyaline cartilage morphologically and histologically.

The clinical relevance of continuous passive motion treatment to manipulative therapists facilitating articular cartilage healing and joint range of motion is evident, since mobilisation is a form of passive movement.

(iii) Reduction in disc herniation

The theory of disc reduction was initially put forward by Cyriax (1971) based partially on the observations of Matthews and Yates (1969) using epidural venography before and after high velocity thrusts. They reported a reduction in the size of small disc protrusions on two patients. However, two control subjects treated by low-velocity mobilisations did not demonstrate any diminution in the size of the concavity produced by small disc deformities. Corrigan and Maitland (1983) advocated intense repetitive oscillations of spinal joints, in the light of clinical improvement for patients with documented evidence of disc prolapse and neurological deficit. In contrast, Farfan (1973) demonstrated that rotatory manipulative techniques did not affect the appearance of disc protrusion as seen in a myelogram. Moreover, this author reported that manipulative techniques occasionally caused enlargement of the disc defect, and some 30 to 50% of patients experienced relief of symptoms even though the myelographic defect was unaltered in appearance. Corrigan and Maitland (1983) acknowledged that what was actually being achieved was uncertain and that prolapsed disc material could not be returned to its original site.

In conclusion there remains considerable scepticism concerning this theory especially since the clinical studies by Christman et al (1964) and Cassidy et al (1985) have demonstrated that disc herniation patients respond relatively poorly to manipulation.

(iiii) Spinal joint "subluxation"

The correction of vertebral subluxations and dislocations from traumatic injury brought about by fracture and/or ligament rupture resulting in a biomechanically unstable segment is another mechanical mechanism that has been attributed to spinal mobilisation (Nyberg, 1993).

The main problem however is their detection. White and Panjabi (1990) questioned the possibility of correcting a vertebral or zygapophyseal joint alignment when evaluative measures are unable to identify a positional problem. Moreover, Zusman, (1986) was unable to demonstrate a higher incidence of spinal joint subluxation in patients with spinal pain compared to pain-free individuals. Therefore, the concept of subluxation, mainly used in chiropractic, is difficult to accept. The lack of a precise, quantitative definition and the failure to scientifically substantiate a vertebral subluxation disorder anatomically or biomechanically relegates the existence of such a problem to belief or theory.

3.3.2 Neurophysiological mechanisms, relief of muscle pain or spasm

Aside from mechanical effects, spinal manipulation or mobilisation are believed to produce changes in neurophysiological activity in tissues. Improvement in spinal mobility following manipulative therapy may not relate to the biomechanical effects on tissue, but to a reduction in pain. Wyke (1967) described the scientific basis for pain relief after spinal manipulation. This author described the existence of four types of synovial joint receptors. Types I, II and III are classified as mechanoreceptors which function to convert mechanical stimuli into electrical signals. Mechanoreceptors offer positional and kinetic information from the respective joint structure to the central nervous system. Type IV receptors are nociceptors and responsible for signalling pain. According to the Gate Control theory proposed by Melzak and Wall (1965), mediation of incoming stimuli through afferent fibres from the various body tissues, somatic and visceral, occurs in the cells of the substantia gelatinosa which, in turn, depresses nociceptive activity. Wyke (1976) suggested that the reflexogenic effect was one of reciprocally co-ordinated inhibition of the muscle tone and stimulation of the stretch reflexes in the muscles. This resulted in a reduction in muscle spasm and therefore an improvement in the range of movement and reduction of pain. Therefore this author postulated that repetitive oscillatory mobilisation movements would

stimulate the mechanoreceptors in the zygapophysial joint capsules causing reflexogenic and pain suppression effects.

A number of studies have reported a decrease in muscle activity in patients after chiropractic manoeuvres using surface muscle electrical activity measurement techniques (Grice, 1974; Grice and Tschumi, 1985; Shambaugh, 1987). These clinical studies provide some experimental support to the hypothesis put forward by Wyke (1976). However, Extrapolating from these manipulation studies that mobilisation would produce a similar effect is premature, especially as these studies all suffer from small sample size, methodological problems and low statistical power. No studies investigating a decrease in muscle activity, using mobilisation techniques, could be found in the literature, indicating the need for clinical research in this area.

3.3.3 Psychological effects of manipulative therapy

The patient's pain behaviour and description sometimes suggest a strong emotional factor in low back pain problems. The growing recognition of the close relationship between psychosocial and psychological factors with back pain and its related disability especially in chronic LBP has resulted in a closer attention to the psychological effects of manipulative therapies. Therefore effectiveness of a manipulative approach must be based on two components; on one hand objective clinical changes such as range of motion and on the other hand the patient's report of pain.

The tactile nature of spinal manipulative therapies is acknowledged to have a powerful psychological effect (Tobis & Hoehler, 1983). Manipulative therapy clinicians have historically attempted to provide a rational for the effectiveness of spinal manipulative

therapies based on mechanical and neurophysiological mechanisms. However, many studies have not appreciated the degree to which "the laying on of hands" may contribute to pain relief. Further reinforcement of the psychological effect of spinal manipulative therapy is exhibited through the interest and concern of the evaluator during the examination. Advising patients about the nature of the condition as well as informing them about what they don't have alleviates unnecessary anxiety and fear (Kane et al, 1974). Furthermore during most high velocity thrust procedures and some low velocity mobilisation procedures an audible sound occurs. The pop, snap or clunk may signify to the patient that a correction has been made (Nyberg and Basmajian, 1993). Patients frequently associate the sound with a repositioning or movement of a vertebra. The type of sound is often predictive of the event that occurred and therefore has meaning to the therapist as well. However, psychological dependence on sounds produced by manipulative therapy is not desirable as an association of joint noise with correction of the problem may place the clinician in a situation where the patient desires repetitive prolonged manipulation or mobilisation, a treatment strategy most would not recommend.

3.4 Clinical Effectiveness studies on spinal mobilisation techniques

3.4.1 Introduction

In spite of the widespread use of mobilisation techniques by physiotherapists in clinical settings, very little is known about the efficacy of these procedures. In contrast there have been several attempts to evaluate the effectiveness of spinal manipulation therapy by reviewing the literature using the technique of meta-analysis (Ottenbacher and DiFabio, 1985; Koes et al, 1991; Shekelle et al, 1992; and Anderson et al, 1992). Overall these studies indicated that spinal manipulation therapy was better than the treatment it was compared to. However, no attempt was made to clearly distinguish mobilisation from

manipulation and several studies combined the two forms of therapy. Moreover, the average methodological score of the studies included was low (Koes et al, 1991; Shekelle et al, 1992).

DiFabio (1992) published the first review on effectiveness studies in OMT where a distinction was made between manipulations (high-velocity thrusts) and mobilisations (low-velocity thrusts) techniques. This author found that the vast majority of valid efficacy studies (11/14) involved some form of manipulation as the primary intervention. In contrast, only 22% (2/9) of the studies with negative results (i.e. no difference between control and manipulative therapy groups) utilised high velocity thrusts as a primary intervention. There is therefore a growing body of evidence for the effectiveness of manipulation in the treatment of LBP. Moreover, DiFabio found only four acceptable efficacy studies of mobilisation as a primary intervention. One study (Nwuga, 1982) indicated a positive outcome while three studies reported no significant difference between groups receiving mobilisations and controls (Zylbergold and Piper, 1981; Bergquist-Ullmann and Larsson, 1977 and MacDonald and Bell, 1990). In summary, DiFabio concluded that additional work is needed to establish mobilisation as an effective therapy, with the balance of evidence currently showing that mobilisation has little effect.

Following on from the work of DiFabio (1992) the present review has sought to identify those trials that were deemed to be valid investigations of treatment efficacy. These papers will be reviewed in the next section and used to establish whether there is evidence to suggest that LBP-patients benefit from low velocity mobilisations.

3.4.2 Scope of search and characterisation of treatment delivered

The literature was searched through computer assisted bibliography methods including Medline and CINAHL databases (1960-1998), plus a manual search of bibliographies of

original and review articles and appropriate Internet resources for all studies including mobilisations. Some of these studies also allowed comparison between manipulations and mobilisations. Studies reporting only manipulations (high velocity thrusts) were omitted.

A sufficient description of the intervention was required to properly identify and categorise studies using mobilisation (low-velocity joint movements within the available RoM) and manipulation (high-velocity thrusts momentarily exceeding the available RoM) or a combination of these two techniques. Nwuga (1982) for example used a "lumbar oscillatory rotation in a push-relax sequence" that fits the operational definition for mobilisation stated above. However, the term "manipulation" did not always correspond with the operational definition. Coxhead et al (1981) for example, used the term "manipulation" but described graded articulations that were more consistent with the definition of mobilisations. Therefore, the description of the procedure took precedence over the label applied to the type of manipulative therapy. In some cases, the authors cited references that were a compilation of many OMT procedures rather than specifically outlining the intervention within the text of the report. Unless stated otherwise, an author's reference to the treatment techniques of Maitland (1986) or Kaltenborn (1993) was considered primarily mobilisation. In contrast, manipulative therapy was attributed to a reference of "Chiropractic or Osteopathic" treatment. Potentially relevant studies were identified on a broad basis. The review includes studies without a control or comparison group, a specific statement indicating blinded assessment, a statistical analysis of outcome measures and with no description of statistical power justifying adequacy of the sample size. In addition, single-subject design studies, where a proper baseline score was reported, are also included. These broad search criteria were used in order to find a sufficient number of studies investigating mobilisations and to obtain a realistic picture of the contemporary published research relating to mobilisation techniques.

Study	Sample Size (Age range)	Intervention	Outcome Measures Used	Control Group	Conclusion
1. Doran & Newell (1975)	456 (20-50)	Mobs. & Manips. vs. Physiotherapy vs Corset vs Control	Patient Self Assessment Finger -to-Floor Straight-Leg-Raising (SLR)	Analgesics and Postural Advice	No difference between groups initially, at 3, 6, 12 weeks and at 1 year follow up
2. Bergquist-Ullmann and Larsson (1977)	217 (20-45)	Mobilisation vs. Back School vs.Control	Functional limitation Questionnaire RoM-test(Schöber) Pain-Index Pain intensity and Quality of pain SLR Work absence rate	Low Intensity Short Wave Diathermy	Both Mobilisation and Back School, more effective than placebo. No difference between Back School and Mobilisations
3. Sims-Williams et al. (1978)	94 (20-65) Patients attending general practice	Mobs and Manips, +Traction vs.Control	Pain Scale, RoM, SLR (goniometer)	Low Intensity Microwave Radiation for 15 minutes	Greater improvement initially, no difference after 1 year
4. Sims-Williams et al.(1979)	94 (20-65) Patients attending rheumatology clinics	Mobs and Manips, +Traction vs. Control	Pain Scale, RoM, SLR (goniometer)	Low Intensity Microwave Radiation for 15 minutes	No differences between groups at all times
5. Coxhead et al. (1981)	334 (average 42)	Mobilisation vs Traction vs, Exercise vs Corset vs Control	Pain scale + Pain questionnaire	No Treatment	Each treatment showed a small benefit over spontaneously improvement rate. No beneficial effects of treatment at 4 and 16 months
6. Zylbergold and Piper (1981)	28 (25-65)	Mobilisation + Traction vs Exercises vs Control	Pain scale SLR RoM Functional Outcome measures	Back Care Instruction	No difference between the 3 groups
7. Nwuga (1982)	51(20-40)	Mobilisation vs a combination of short wave, Exercises and Back Care instruction	SLR Lumbar Motion	No control group	Treatment group required less treatments and had greater improvements
8 Farrell & Twomey (1982)	48 (20-65)	Mobs.& Manips. (predominant mobilisations) vs. a combination of Microwave, Exercises and Back Care instruction	Pain-scale Functional limitations questionnaire Spondylometer SLR	No control group	Mobs. and Manips group less days to become symptom free. No difference in impairment measures
9 Waterworth & Hunter (1985)	108 (18-50)	Mobs.& Manips. +Mac Kenzie exercises vs. analgesic and heat+ ergonomic advice	4 point scale of functional disability, pain severity and treatment effectiveness RoM in Flexion and Extension	No control group	No statitical differences between the groups
10. Gibson et al. (1985)	109 (average 36)	Mobs.& Manips. vs. short wave diathermy vs control	Pain scale RoM	Detuned Shortwave Diathermy	No statistical difference between groups
11. Hadler et al. (1987)	54 (18-40)	Mobilisation vs. Manipulation	Disability questionnaire and VAS-scale	No control group	Manipulation group improved more rapidly than mobilisation

12. Ongley et al. (1987)	81(21-70) Chronic LBP > 1 Year	Manipulation + Sclerosing injections vs. Mobilisation + Saline injections	Disability + pain questionnaire	No control group	Greater improvement in disability and pain scores in manips group than in mobilisation group
13. Mathews et al. (1987)	164 (18-60) 132 with SLR limitation 32 without SLR limitation	Mobs.& Manips. vs.control	Pain Scale SLR RoM	Infra-red treatment	Hastening of pain relief within first 2 weeks over control group. Most marked for patients with SLR limitation
14. MacDonald et al. (1990)	95 (16-70)	Mobilisation & Manipulations vs.control	Disability Questionnaire Pain Analog Scale Activity Loss Score	Reassurance and postural advice	Significant difference at 2 weeks not at 4 weeks
15. Meade et al. (1990)	741 (18-65)	Mobilisation versus Manipulation	Disability + Pain Questionnaire SLR Lumbar flexion	No control group	Manips. group improved more on disability score than mobilisation
16. Beattie (1991)	Single Subject Design ABAB design	Maitland mobilisations	Left-side lumbar flexion Knee-to-floor measurement	Not Applicable	Significant improvement in left-sidebending during intervention phases
17. Blomberg et al. (1994)	101 (20-60)	Mobs.& Manips. +steroid injections +stretching vs. activation therapy and return to work	RoM (no instruments used) SLR Pain on movement	No control group	Significantly greater improvement in intervention than comparative group
18. Skargren et al. (1997)	323 (18-60)	Mobilisation combined softtissue treatment and exercises vs manipulation	VAS General Health Sick-leave Disability score Patient satisfaction with treatment	No control group	Only on patient satisfaction rating, manipulation significantly better than combination of mobs and physio. Trend for manips. to have higher effect than mobs., immediately after treatment
19. Enebo (1998)	Single Subject Design AB design	Moist Heat Pack Myofascial Release Side Posture Push-Pull Mobilisation	Quebec Back Pain Disability Questionnaire Pain Threshold Algometer VAS- Scale	Not applicable	Pain Threshold increased Functional disability and pain intensity decreased initially Pain intensity followed a cyclical pattern No effect after 30 days

Table 3.1 Summary Table of Clinical Spinal Manipulative Therapy Trials (Trials including Mobilisation)

3.4.3 Results

The results of this literature search are presented in table 3.1

(i) Controlled studies on the effect of Mobilisation or a combination of Mobilisation and Manipulation on Low Back Pain

A total of 9 studies out of 17 selected comparative studies (excluding the single-subject design studies) used a control group. Five studies reported positive results i.e. mobilisations or combination mobilisations & manipulations had a greater effect than the control treatment. Four could not report any difference between controls and mobilisation or a combination of mobilisations & manipulations. Of the 5 with positive effect 2 used mobilisation as a separate treatment (Coxhead et al, 1981; $p<0.05$; Bergquist-Ullmann and Larsson, 1977; $p<0.05$) whereas the 3 others used a mixture of mobilisations and manipulations. (McDonald et al, 1990, $p=0.06$; Sims-Williams et al, 1978, $p=0.005$ and Mathews et al, 1987, $p<0.01$). One controlled study with a negative result used pure mobilisation (Zylbergold and Piper, 1981; $p=0.18$) whereas three were mixed studies (Gibson et al, 1985; $p>0.05$; Sims-Williams, et al, 1979, $p>0.05$ and Doran and Newell, 1975; $p>0.05$)

It would appear from the above that there is weak scientific evidence for mobilisations having a greater effect on low back pain than a control treatment. However, 6 out of nine studies used a combination of mobilisation and manipulation making it difficult to know which was the effective intervention. Nevertheless, in the two studies where mobilisation techniques were used as separate interventions (Coxhead et al, 1981 and Bergquist-Ullmann & Larsson, 1977), mobilisation showed to be significantly better than the control treatment which consisted of no treatment, in the study by Coxhead and detuned short wave in the study by Bergquist-Ullmann & Larsson .

(ii) Studies Comparing Manipulation with Mobilisation

Four studies were retrieved from the literature where the treatment effects of mobilisations and manipulations were compared.

Meade et al (1990) conducted a pragmatic multicentre trial to compare and contrast private chiropractic care (n=378) with conventional hospital outpatient management (n=339) provided by physiotherapists to patients with low back pain. This study was essentially a comparison of high-velocity, low amplitude thrusts used by chiropractors and low-velocity mobilisations used by physiotherapists. However, a minority of physiotherapists sometimes included high-velocity thrusts as a treatment technique.

The results suggest that high-velocity treatment was significantly more effective than hospital outpatient management using predominantly mobilisation, with respect to decreasing pain and improving mobility. Moreover, the benefits of chiropractic care (manipulation) continued to be superior to hospital-based treatment for 6 months to 2 years following intervention.

This study has been highly criticised by the physiotherapy community as flawed in study design and conclusions (Wise, 1990) e.g. it was noted that patients seen by chiropractors received 44% more treatments compared with those seen in the hospital. Furthermore, the early intervention and specialised care provided by chiropractors working in a private clinic were contrasted with the longer waiting times for initial appointments and more generalised care provide in a socialised system (Saunders, 1991; Paris, 1991). However, the authors emphasised the "pragmatic" nature of the study i.e. allowing the therapist to choose from a range of techniques, which is closer to established practice, and less open to criticism than when the treatment is to be decided artificially. Moreover, Erhard (1991), in a commentary to this study, stated that the most important findings were the advantage of early

intervention and the advantage of high-velocity thrusts over low-velocity thrusts. He concluded that the long-term result was not surprising and, in fact, had already been demonstrated in an earlier, smaller (but better controlled study) by Hadler et al (1987). In this study, which had an above average score in design (Koes et al, 1991), fifty-four subjects were randomly assigned to one of two groups. One group received manipulation (n=26) and the control group (n=28) was given mobilisation of the lumbar spine without a thrust. A total of five treatments sessions was provided within 2 weeks from the beginning of the project. Subjects who experienced symptoms for only 2 to 4 weeks prior to receiving manipulation reported greater and more rapid decrease in disability and pain compared with subjects receiving mobilisation. These results were based on the subjects' responding to a disability questionnaire and a visual analogue pain scale.

Ongley et al (1987) compared two groups. An experimental group (n=40) receiving sclerosing injections together with a single forceful rotational manipulation. This procedure was followed by weekly proliferant injections and lumbar flexion exercises for a total intervention dispersed across 6 weeks. The control group (n=41) received a "non-forceful manipulation" (mobilisation) of the lumbar spine with injection of a placebo(saline) proliferant and a reduction of analgesics. The experimental group reported greater improvement in disability and pain scores compared with the control group 6 months following treatment. These data were based on the patients' response to a disability questionnaire. Manipulations were thought to be responsible for rupturing micro-adhesions that had formed in response to connective tissue immobilisation. However the manipulation group also received sclerosing injections and lumbar spine exercises while the mobilisation group did not which makes the results questionable.

A more recent study by Skargren et al, (1997) compared the cost and effectiveness of chiropractic and physiotherapy treatment for LBP and neck pain combined. Physiotherapy

treatment included several treatment methods but mobilisations and soft tissue treatment formed the dominant part (72%) of all techniques used. Outcome measures were primarily changes in pain intensity and general health, assessed with visual analog scale and a disability questionnaire. Direct and indirect costs were measured. The effectiveness and total costs of chiropractic and physiotherapy as primary treatment were similar after treatment and after 6 months. However, patient satisfaction rate was significantly higher in the chiropractic group. In addition, immediately after treatment, there was a trend for manipulations to have a greater effect than mobilisations. No impairment outcome measures were used.

In conclusion 3 out of 4 studies indicated that manipulation may be superior to mobilisation and one study was inconclusive. Nevertheless, conclusive evidence, as to the superiority of manipulation over mobilisations, are premature as all the studies were of poor scientific quality, judged by the criteria used by Koes et al (1991). Furthermore, all these comparative studies used subjective outcome measures and none used valid objective measurements for RoM. to determine outcome.

(iii) Studies comparing mobilisation with other forms of treatment (other than manipulation)

Four studies were found in the literature in which mobilisation was precisely enough described to distinguish it from manipulation and where it was compared to other than manipulation treatments.

Bergquist-Ullman and Larsson's (1977) trial is one of the more rigorously conducted with long-term follow-up and an extremely low drop-out rate. However, the trial was limited to an occupational setting and reported on factory workers with subacute LBP(n=217), presenting to an occupational clinic. Mobilisation was compared with a back school of four

sessions and a placebo-control treatment (low intensity short wave therapy). A modified Schöber test was used to measure back mobility. Functional limitation was rated on a 4-point scale and pain was assessed for quality and intensity. In addition a straight-leg-raising test (SLR)-test was performed and absence from work, on account of LBP in the following year, was recorded. Analysis was by intention-to-treat. Back school and mobilisation produced similar outcomes, and both were significantly more effective than the placebo treatment. However the placebo element of both mobilisation and back school could be considerable due to the (different) kind of attention paid to the patient in each of the treatments.

Coxhead et al (1981) in a controlled trial (no treatment) compared mobilisation with traction, exercise and corset treatment including 334 sciatica pain patients. Pain relief, reported subjectively by questionnaire, was used as an outcome measure. These authors found no difference in improvement between mobilisations and the 3 other treatment forms. However a small degree of benefit over spontaneous improvement was found but this was true for all treatments and no benefit over spontaneous improvement was perceived at 4 and 16 months.

Zylbergold and Piper(1981) used back care instruction only, as a control group, in a study where they compared mobilisation combined with traction to an exercise regime over a one-month period (n=28). Simple objective measurements for spinal mobility were used in addition to functional outcome measures. No difference between the 3 groups in terms of pain, spinal mobility and functional activity were reported

The work of Nwuga (1982) was the only study which reported a significant benefit of mobilisation over a conventional method of management of back pain (heat, pelvic tilt exercises, postural education and lifting instructions). Fifty-one patients, aged 20-40, with disk protrusion confirmed by myelographic and electrodiagnostic tests and nerve root

compression inferred by lower-extremity reflex changes were included. No subjective outcome measures were used. Measurement of spinal flexion, extension and side-flexion were done by using a spondylometer and recorded before and after the four week intervention period for each subject. Lumbar rotation was measured with the subject sitting on a chair and the interscapular line fixed relative to the thorax. Lumbar rotation was measured as the angle between the interscapular line and the frontal plane as the subject rotated the trunk on either side. The interscapular line was stabilised relative to the chest by resting the horizontally extended arms on a long stick which was positioned across the back at the scapular level. Nwuga reported that the mobilisation group showed significant increases in lumbar motion and SLR compared with controls. The functional significance of improvement in lumbar motion and SLR however, was not described.

In conclusion only one non-controlled study showed a clear benefit for mobilisation over conventional physiotherapy treatment. Three other studies failed to prove that any additional benefit could be attributed to mobilisation over other treatment interventions.

(iiii) Studies comparing a combination of mobilisation and manipulation with other forms of treatment or control group.

Doran and Newell (1975) published one of the first controlled multicentre trials on the treatment effect of a combination of manipulation and mobilisation (n=456). The techniques used were at the discretion of the manipulator but included mobilisation and soft-tissue techniques as well as high velocity thrusts. Three groups were compared (i) mobilisation/ manipulation (ii) conventional physiotherapy which included any "treatment which is usual in a physiotherapy department" and (iii) corset treatment. The control treatment consisted of analgesics and postural advice. Finger-to-floor, 6-point pain scale and patients

assessment of "better" were used as outcome measures. No significant differences between the 4 groups initially, at 3, 6, 12 weeks and 1 year follow-up were reported.

Two other studies were reported by the same author (Sims-Williams et al, 1978 & 1979) It is interesting to observe that although the same research methodology was used in these two studies, patients in the 1978 study attended a general practice (n=94) and those in the 1979 study a rheumatology clinic (n=94). Patients were allocated at random to either mobilisation and manipulation or placebo treatment (low intensity microwave). SLR and spinal movements were measured with a goniometer. Results were assessed immediately after the treatment course, two months later, and at one year. Opposite results were reported in the two studies. The 1978 study reported in favour of mobilisations whereas the 1979 study could not find any difference between the experimental and control groups. It was concluded from these studies that patients referred to specialist clinics in hospitals would have a longer duration and more severe symptoms than those cared for by the general practitioners, and might be less likely to benefit from mobilisation & manipulation treatment.

Farrell and Twomey (1982) reported on a controlled trial where the experimental group was a combination of mobilisation and manipulation, whereas the control group was given microwave diathermy, abdominal exercises and ergonomic instructions. Patients were considered symptom-free when all functional activities could be performed essentially without pain and when measurement of lumbar movement (measured with a spondylometer) and SLR (measured with a goniometer) could be made without a report of pain. The group receiving mobilisation and manipulations achieved symptom-free status approximately 1 week sooner than the control group. However, 91% of all the subjects recovered from their symptoms within 4 weeks which is in agreement with the figures reported by Frymoyer (1988).

Waterworth and Hunter (1985) compared conservative physiotherapy (heat-shortwave and ultrasound combined with a programme of active flexion and extension with a manipulation/mobilisation group and a group which received non-steroidal anti-inflammatory drugs. No pure control group was used. No statistically significant differences between the groups were reported ($p>0.05$). Gibson et al (1985) compared 109 patients in a controlled study where they used a lumbar mobilisation and manipulation group and compared these to a group which got short wave diathermy. Detuned short wave was used as a control. Reduction of pain and improvement of spinal movement (measured with VAS and finger-to-floor method) were similar in the 3 groups. Mathews et al (1987) divided a sample of patients into two groups: One group of subjects (n=132) had limited passive SLR, and the other group of subjects (n=33) had no SLR limitation. Mobilisation and manipulation were given daily "if indicated" for 2 weeks. Control groups (one group with and the other without limited SLR) were given infrared treatments for 15 minutes, three times weekly. All groups were presented with instructions for proper lifting and "offered a spinal corset". Subjects with SLR limitations showed significantly higher recovery rates based on pain scores compared with subjects in the control group without SLR limitation. In contrast, there was no difference in recovery between mobilisation and manipulation and control groups for subjects without initial SLR limitations. The relatively small sample size for the experimental group (n=33) without SLR limitations and the loss of statistical power were discussed as factors contributing to the negative findings in this component of the study (DiFabio, 1992).

MacDonald and Bell (1990) in a controlled trial (n=95) of an above average quality demonstrated responsiveness to a combination of high velocity and low velocity thrusts in some patients presenting with pain durations of 14 to 28 days. Both groups received advice on posture, exercise and avoidance of occupational stresses as appropriate to their situation.

The control group were seen in the clinic as necessary for examination for incapacity certificates and reassurance. Control patients were told that there was no treatment that had been shown to be superior to the programme of rest and graded resumption of activities on which they embarked. The treatment effect was evaluated by a disability index (12 items) questionnaire and Pain Scale. The advantage to the manipulated/mobilised group was maximal between 1 and 2 weeks after commencing treatment, but was not discernible after 4 weeks although none of the differences reached significance level of $p<0.05$.

In a more recent trial, Blomberg et al (1994) compared the effectiveness of conservative treatment for back pain including drug therapy, the continuation of normal activity by patients , back exercises, corsets and TENS, but excluding bed rest with an experimental treatment consisting of mobilisation and manipulation combined with steroid injections. Unfortunately the measure of quality of life (24 variables of daily life measured on a VAS scale) which these researchers used does not appear to have been validated (Evans & Richards, 1996). Patients, receiving the experimental treatment in this trial had a better outcome in terms of the amount of sick leave at the time of the LBP episode and during the following eight months. However, although the authors reported a statistically significant difference between the groups on this measure, it is difficult to assess whether the differences are clinically significant.

(iiiii) Single-Subject-Design Studies

Two single-subject-design studies dealing specifically with mobilisation techniques were retrieved from the literature. Beattie (1991) used an ABAB (A= baseline, B= intervention) single case design to assess the effectiveness of Maitland spinal mobilisation techniques. Left-side lumbar flexion was taken as the dependent variable. This was measured by using the knee to floor distance. It was concluded that Maitland spinal mobilisation techniques

were effective in the short-term treatment of low back pain, although it was suggested that further studies should re-examine subjects at set periods following termination of treatment to assess long-term effects. Aufdemkampe (1991), in a commentary to this article stressed the importance of objective and reliable and valid measurement instruments especially in single case studies.

Enebo (1998) used a BA design where the patient was treated five times during 3 weeks by a combination of moist heat, myofascial release and side-posture push-pull mobilisation. Disability questionnaires, VAS scales and pressure pain thresholds were used as outcome measures. During intervention, functional disability and pain intensity decreased and pressure-pain thresholds of the lumbar spine increased. During follow-up, functional disability and pain intensity initially decreased. However, both increased by the end of the follow-up phase. This study used only one examination session to establish baseline levels of mobility. As the establishment of a baseline is of paramount importance in the design of a Single Subject Study the results of this report have to be interpreted with caution.

3.4.4 Conclusion

This analysis of the literature on mobilisation techniques identified 19 studies that were judged to be demonstrations of efficacy or non-efficacy in the treatment of low back pain by mobilisations or a combination of mobilisation and manipulation. The primary criterion for inclusion in the analysis was the clear description of the intervention used. This description of the intervention would allow clear identification of mobilisation techniques as a treatment intervention either on its own or in combination with manipulation techniques.

By evaluating these studies we wanted to answer five questions:

1. Is there scientific evidence in the literature that mobilisation or a combination of mobilisation and manipulation is more beneficial than control treatment?

2. Is there scientific evidence in the literature that mobilisations are more or equally beneficial in the treatment of low back pain than manipulations?

3. Is there scientific evidence in the literature that mobilisations are more or equally beneficial in the treatment of low back pain than comparative forms of treatment other than manipulations?

4. Is there scientific evidence in the literature that mobilisations combined with manipulations are more or equally beneficial in the treatment of low back pain than other forms of treatment or control group?

5. Is there further scientific evidence from comparative studies that mobilisations are effective in the treatment of low back pain ?

From this overview it would appear that there is weak scientific evidence for mobilisation or a combination of mobilisation and manipulation in an intervention group to be more beneficial in the treatment of low back pain than conservative treatment or a control group. However, when studies using mobilisations alone were compared with either manipulations or with other treatment, only one study was found demonstrating a significant benefit of mobilisations over conventional physiotherapy treatment (Nwuga et al, 1982). None of the seven other studies was able to reveal any advantage of applying mobilisation over manipulations or another treatment form (Bergmann-Ullmann & Larsson, 1977; Coxhead et al, 1981; Hadler et al, 1987; Ongley et al, 1987; Meade et al, 1990; Skagren et al, 1997 and Zylbergold & Piper, 1981).

When comparing Orthopaedic Manipulative Therapy (mobilisation and manipulation combined) with a comparative treatment, 4 studies yielded a negative result (Doran & Newell, 1975, $p>0.05$; Sims-Williams, 1979, $p>0.05$; Waterworth & Hunter, 1985, $p>0.10$ and Gibson et al, 1985, $p>0.05$) whereas 5 reported a beneficial result (Sims-Williams,

1978, $p<0.05$; Farrell-Twomey, 1982; $p>0.001$; Mathews et al, 1990; $p<0.01$; MacDonald and Bell, 1990; $p= 0.06$ and Blomberg et al, 1994; $p=0.035$). This trend is similar to the consensus, reported in several meta-analyses, on manipulation as a sole intervention (Ottenbacher and DiFabio, 1985; Koes et al, 1991; Shekelle et al, 1992 and Anderson et al 1992).

Table 3.1 shows that there are large variations among the different studies in sample size, characteristics and outcome measures used. Moreover, none of the studies were double blind trials. This was difficult because patients were aware of whether they had manipulative therapy or not. In fact Doran & Newell (1975) reported that the assessing physician inadvertently discovered the treatment in about 10% of the cases. Furthermore, a proper control is essential in clinical trials because of the natural resolution of low back pain and the placebo effect associated with the treatment (DiFabio, 1986; Koes et al, 1991). Several studies did not employ a control group (Blomberg et al , 1994; Skargren et al, 1997; Meade et al, 1990; Ongley et al, 1987; Hadler et al 1987; Waterworth & Hunter, 1985; Farrell & Twomey, 1982; Nwuga, 1982). Although control groups were employed in other studies they were sometimes improper (Doran & Newell, 1975; Bergquist-Ullmann & Larsson, 1977, Sims-Williams, 1978 & 1979 and Mathews et al, 1988). They mainly consisted of thermal therapy or analgesics which might also produce therapeutic effects. Another deficiency of clinical trials involving mobilisations and manipulations is a lack of proper outcome measures. Most of the studies reviewed in the present survey reported subjective pain relief measures combined with some sort of disability questionnaire. The study by Nwuga (1982) was an exception is this respect as it only reported on objective outcome measures.

Thirteen of the 19 studies employed simple objective criteria such as improvement in spinal mobility and SLR (Doran & Newell, 1975; Bergquist-Ullmann & Larsson; Sims-Williams,

1978 & 1979; Zylbergold & Piper; (1981); Nwuga, 1982; Farell & Twomey, 1982; Waterworth & Hunter, 1985; Gibson et al, 1985; Mathews et al, 1988; Meade et al, 1990; Beattie, 1991; Blomberg et al, 1994). Mobility measures were of a simple one-or two-dimensional nature and with questionable reliability and validity. Functional outcome measures were reported only in the study of Zylbergold and Piper (1981). Outcome measures such as return-to-work rate or use of sick leave were used by Skargren et al, 1997; Blomberg et al, 1994 and Bergquist-Ullman & Larsson, 1997. These types of outcomes in combination with more reliable 3 dimensional impairment measures should receive more attention in future studies on OMT because they allow for a more meaningful description of the efficacy of OMT and collateral interventions. In addition the validity and reliability of outcome measures used should be clearly stated.

Despite the deficiencies identified in these clinical trials on mobilisation or a combination of mobilisation and manipulations it may be generally concluded that there is weak scientific evidence that mobilisations or a combination of mobilisations and manipulations have a slightly better outcome on the treatment of low back pain than pure or placebo controlled treatments.

There is however no scientific evidence that mobilisation alone is more beneficial in the treatment of low back pain than a comparable intervention. Furthermore, the evidence from this literature survey suggest that lumbar spinal manipulation appears to hasten the rate of improvement in pain, spinal mobility and functional impairment to a greater extent than with mobilisation techniques alone.

In conclusion the limited evidence on the effect of mobilisations in low back pain is of poor methodological quality with measures of limited value. In order to investigate the scientific

merit of lumbar mobilisation techniques more studies are required which have high methodological quality and which use scientific and appropriate outcome measures.

3.5 Summary and conclusion on effectiveness of mobilisations

- Several working hypotheses for the use mobilisations in the treatment of LBP have been put forward by different authors. However, there is a dearth of valid explanatory research that helps to identify the mechanism of how mobilisation techniques might alleviate LBP and increase range of motion. The lack of consensual research findings may be due to the difficulty of diagnosing the precise source of the symptoms and a high incidence of both spontaneous recovery and re-occurrence of symptoms.
- This analysis of the literature pertaining to manipulative therapy, identified 19 studies that were deemed to be valid demonstrations of the efficacy or non-efficacy of mobilisations in the treatment of low back pain. Overall, there was no clear evidence for the use of these procedures in the treatment of low back pain. Only one of the four studies, investigating mobilisation alone, supported the use of mobilisation as an intervention with a greater effect than a comparative treatment.
- When mobilisation was compared with manipulation no evidence was found to justify the use of mobilisations in the treatment of low back pain. In contrast manipulation proved to be a more effective treatment procedure in 3 out of 4 studies.
- Although the studies investigating the effect of mobilisation and manipulation combined indicated that these patients may possibly recover more rapidly than those receiving placebo, the question of the separate effect of mobilisations remains.
- Most of the trials suffer from a lack of objective outcome measures. Subjective pain relief reported by the patients either orally or in questionnaires formed the main outcome measure in most trials. Some studies had employed simple objective criteria such as

improvement in spinal mobility and straight leg raise but none had used more comprehensive methods like three-dimensional mobility testing. Although disability questionnaires were used functional outcome measures were only reported in the study by Zylbergold and Piper, (1981).

- There was a paucity of valid research on the effect of mobilisation techniques in the treatment of low back pain. As these techniques are at the core of most of the physiotherapy treatments for LBP it is imperative for the profession to provide evidence of efficacy of these treatments or to discard them from their armamentarium of treatment alternatives.

4. Normative Values in 3 Dimensional Kinematics of the Lumbar Spine

4.1 Introduction

Evaluation of impairment of the spine involves diagnosis-related factors (i.e. structural abnormalities) and musculoskeletal/neurological factors that require physiological measurements (Dopf et al, 1994). The American Medical Association guide to evaluation of permanent impairment of the spine includes measuring range of motion using the double inclinometer technique (Engelberg, 1988). However, given the importance placed on spinal motion, the most accurate, objective and cost-effective method for measurement should be used so that maximum information on spinal kinematics can be obtained. The development of a good measurement of spinal motion is complicated since movement occurs at several motion segments, which articulate at different levels around different axes of rotation and may hence produce movement in three dimensions. As the spine is a 3 dimensional structure, 3 dimensional measurement of lumbar motion has gained more widespread acceptance. This approach allows the clinician and researcher to record a more comprehensive picture of the way the spine moves than that produced by recording RoM alone.

Measurement in medicine is frequently used as part of the diagnostic process, an "abnormal" value alerting the clinician to the possibility of a disorder or disease. To consider a measured value "abnormal" (unusual) presupposes a knowledge of what is "normal" (usual) (Burton & Tillotson, 1988). In general, diagnostic measures are compared with a set of reference values drawn from a healthy population and measures falling outside the reference range will indicate that closer examination of the patient is warranted.

4.2 Reference values

Reference values for lumbar mobility have, in the past, generally been limited to sagittal measurements and reported as mean values. However, Bezemer et al (1983) described an alternative approach which takes into account the skewness and kurtosis of the observed distribution. They recommended the use of reference "ranges" (or limits of normality) and, furthermore, suggested two limits (as percentiles) towards each end of the distribution, thus emphasising the empirical nature of such limits. Their recommendation was the use of values which remain after removing the top and bottom 2.5% or 10% of the subjects from the collected data i.e. 95% confidence limits or 80% confidence limits. They argued that statistics of these order are simple and readily understood. The reference population should resemble as closely as possible the target population and should exceed 50 individuals. Battie et al (1987) agreed with this and stressed the importance of reporting normative data in the form of descriptive statistics by the use of categories for factors such as age and gender so that subsequent measures can be ranked within the distribution.

The studies presented in this study use reference values (limits) which are in accordance with the recommendations of Bezemer et al (1983). However, some reliability and validity studies are also included despite having a relatively small number of subjects or using a younger age category than the target population for low back pain. The use of weighted means is able to compensate to some degree for the difference in sample sizes between studies.

The aim of this overview is to demonstrate what might reasonably be considered the limits of normality for maximal lumbar 3 dimensional motion, gleaned from a large cross-sectional sample of subjects (from adulthood to the elderly) claiming no history of back trouble, and

being suitably stratified by age and gender. These values have been obtained from a comprehensive review of the literature. The normative values for 3 dimensional lumbar spinal motion measured directly (Table 4.1) will be compared to values from 3 dimensional X-rays studies (Table 4.2) as these are widely accepted as a "gold standard" for comparison in 3 dimensional motion analysis.

In tables 4.1 & 4.2, where a study has reported lateral bending or axial rotation as the full range of motion from one extreme to the other as one overall value, it has been assumed that the data was symmetrically distributed about the neutral position. These values are marked in tables 4.1 & 4.2 with an asterix(*). It is not possible to apply this modification for flexion-extension where symmetry can not be assumed.

Weighted means were calculated by multiplying the values in degrees by the number of subjects in the study. A summation of these products in this way of all studies was divided by the summation of the total number of subjects included in all the studies.

Study 1 Study 2 Study 3

$$\frac{(A \times a) + (B \times b) + (C \times c).....}{(a + b + c + ...)}$$

Where: A, B, C, ... are the values in degrees obtained in different motions

a, b, c..... are the numbers of subjects participating in the studies

(A x a) product for study A e.g. forward flexion, angles in degrees multiplied by number of subjects in the study A

Angles are presented as rounded values i.e. 50.5 degrees = 50 degrees, 50.6 degrees =51 degrees.

Normative Values for 3Dimensional Lumbar Spinal Motion measured directly (in Degrees)

Study	Device Used	Age Range (y)	Inclusion Criteria	Number of Subjects	Flex. °	Ext. °	Flex &Ext °	LBL °	LBR °	SBL& SBR °	AxL °	AxR °	AxL& AxR °
Dopf et al 1994	CA-6000 SMA	20-35	No LBP 12mnths. No Back surgery No prior disability because of LBP	120(60F,60M)	81 (10)	34 (10)	115 (16)	46(7)	45(7)	91(13)	43(7)	42(7)	85(13)
Gomez et al 1991	Isostation B-200	20-50+	No LBP 6 mnths.	168(83F,85M)	61(9)	34(1)	95	37(6)	36(6)	70(12)	36(5)	36(5)	72(10)
Buchalter et al 1986	Isotrak 3Space	20-41	No spinal deformities	60(33F,27M)	56	21	77	23*	23*	47	7*	7*	15(12)
Hindle et al 1990	Isotrak 3Space	20-50+	No LBP 6 mnths No spinal surgery	80(40F,40M)	70	23	93	26*	26*	52	15*	15*	29
Dvorak et al 1995	CA-6000 SMA	20-70	No LBP 12 mnths	104(42F,62M)	63(4)	24 (10)	87(14)	29(7)	30(7)	59(14)	41(9)	41(6)	82(15)
Russell et al 1993	Isotrak 3Space	20-69	No LBP 6mnths No treatment for LBP	200(100F,100M)	67 (10)	21(7)	88(17)	23*	23*	47(10)	15*	15*	31(9)
Esola et al 1996	3D Opto-electronic	23-37	No history of LBP	21(8F,13M)	43 (10)								
Petty 1995	CA-6000 SMA	18-23	Asymptomatic for LBP	18F	74	35	109						
Mc Gregor et al 1995	CA-6000 SMA	25-50	No history of LBP	20(12F,8M)	57 (11)	20 (15)	77(26)	30 (11)	30 (7)	60(14)	25(7)	24(7)	49(14)
Schuit et al 1997	CA-6000 SMA	20-48	No LBP 6mnths	13(9F,4M)	62	21	83	31*	31*	62			
Troke et al 1996	CA-6000 SMA	21-35	No history of LBP	11(4F,7M)			90(10)	30*	30*	61(9)	6*	6*	12(4)
Mean					**63**	**26**	**91**	**30**	**30**	**60**	**22**	**23**	**45**
Weighted Mean					**66**	**27**	**93**	**30**	**29**	**60**	**27**	**27**	**53**

Flex.= Flexion, Ext= Extension ,LBL= Lateral bending to the left, LBR= Lateral bending to the Right, AxL= Axial Rotation to the Left, AxR= Axial Rotation to the Right
* = data assumed symmetrically distributed about the neutral position.

Table 4.1 Normative Values for 3Dimensional Lumbar Spinal Motion measured directly (all in Degrees)

Normative Values for 3Dimensional Lumbar Spinal Motion measured by in-vivo X-Rays (in Degrees)

Study	Device Used	Age Range (y)	Inclusion Criteria	Number of Subjects	Flex °	Ext °	Flex& Ext °	LB L °	SBR °	LBL &S BR °	AxL °	AxR °	AxL & AxR °
Schuit et al 1997	X-Ray	20-48	No LBP history	13(9F,4M)	61	20	81	31	32	62			
Dvorak et al, 1991	X-Ray	22-45	No LBP history	41(18F,23M)			89	29*	29*	58			
Pearcy et al 1985	X-Ray	25-36	No LBP history	11M	51	16	67	17	18	35			
Mean					**56**	**18**	**80**	**26**	**26**	**52**			
Weighted Mean					**56**	**18**	**84**	**28**	**28**	**56**			

Flex.= Flexion, Ext= Extension
LBL= Lateral bending to the left, LBR= Lateral bending to the Right
AxL= Axial Rotation to the Left, AxR= Axial Rotation to the Right
* = data assumed symmetrically distributed about the neutral position.

Table 4.2 Normative values for 3 Dimensional Lumbar spinal motion measured by in-vivo X-rays (all values in degrees)

4.3 Results

4.3.1 Flexion & Extension Values

For the maximum flexion angle a wide range of values was reported in the literature, ranging from 81 degrees (Dopf et al, 1994) to 43 degrees (Esola et al, 1996).

The study by Dopf et al (1994) included 120 healthy subjects and was primarily designed as a reliability study. In addition, Dopf's study was designed to establish normal values for lumbar spinal motion using the CA-6000 SMA. The flexion values reported in this study are markedly (29%) larger than the mean of the other studies in this overview. The reason for this could be that Dopf et al (1994) used subjects in the age categories 20 to 35 which does not account for older subjects. Furthermore, the subjects were predominantly fit, hospital employees, and had no painful body joints. They could therefore have had greater mobility than the general population. The limited age range was chosen in order to have a fairly homogeneous age group as the purpose of this study was to investigate reliability and, in addition to establish normal values of lumbar spine motion.

Loeble, (1967); Moll and Wright, (1971) and Fitzgerald et al (1983) have all documented decreasing spine motion with advancing age and even in the small age window (20-35y) used in Dopf et al's study, the data showed a trend towards a decreasing range of motion with increasing age. Moreover, Dopf et al, (1994) reported significantly larger mobility values for females in all motions except for forward flexion.

In summary, this study, although powerful, reported values well in excess of the average reported by other authors and consequently skewed the data distribution. The narrow age window and type of subject taken were probably the main reasons for this.

At the other end of the range Esola et al (1996) reported flexion values (43 degrees) nearly half of these reported by Dopf et al (1994), (81 degrees). In this study a three-dimensional opto-electronic motion analysis system was used to measure the amount and velocity of lumbar spine and hip motion separately during forward bending. A patient group and an healthy subject group were compared. The results suggested that although people with a history of low back pain have ranges of lumbar spine and hip motion during forward bending similar to those of healthy subjects the pattern of motion was different i.e. patients tended to move more at their lumbar spine during early forward bending and had significantly ($p<0.01$) lower lumbar spine to hip flexion ratios during the middle part of a forward bend. Esola et al (1996) were the only group to measure spinal motion using an opto-electronic or remote sensing methodology and this may account for the low values reported by this study. The remaining studies range between 56 and 74 degrees.

In conclusion, large variations in reported values for 3 dimensional forward flexion exist which makes comparison of values obtained with different devices, and even using the same device, difficult. However, forward flexion measured by 3D devices gives a weighted mean value of 66 degrees and 8 out of 10 trials (including all 3 trials using the 3Space Isotrak) reported values within 10 degrees of this figure. Therefore, it would appear from the literature that approximately 60 degrees of forward flexion can be expected.

Turning to the extension values a similar spread in results can be seen. No studies appeared which reported values substantially less than the weighted mean value (27 degrees). In contrast 3 studies reported values exceeding the mean value by up to 48% (Dopf et al, 1994; Gomez et al, 1991 and Petty, 1995). Gomez et al (1991) used an hydraulic pump controlled lumbar dynamometer (Isostation B-2000). Subjects were secured to this device

in an unique manner which included standing on a platform in an upright, neutral position with the flexion/extension axis aligned with their lumbo-sacral junction and legs secured with straps. This is completely different to the relatively unconstrained test situation when using the 3Space Isotrak or a CA 6000 SMA device. This may have contributed to the larger extension values obtained with this device. Moreover, several of the test subjects completed full extension RoM to the safety stop at 35 degrees, therefore, the distribution of extension measures was likely to be skewed.

The study by Dopf et al (1994) as indicated previously used a young population. In the study by Petty et al (1995) which used the CA-6000 SMA to investigate the effect of a mobilisation session on sagittal mobility of the lumbar spine in asymptomatic subjects, only 18 young female undergraduate physiotherapy students were included and it is likely that this younger age range might have inflated the recorded values. In general the data are in broad agreement that approximately 27 degrees of extension can be expected, taking the whole age spectrum into account.

Dvorak et al (1995) compared their results to those found in an earlier study of lumbar spinal RoM using functional X-ray analysis (Dvorak, 1991). Subjects 60 years and older were eliminated from the comparison so as to achieve a comparison of similar age groups. Similar values (87 and 89 degrees) were measured in flexion/extension and lateral bending with both procedures (tables 4.1 and 4.2).

The studies included in this overview reported a weighted mean for forward flexion and extension of 66 and 27 degrees respectively and a total excursion of 93 degrees. These values are in excess of the X-ray studies (Table 4.1) of Schuit et al (1997), Pearcy (1985) and Dvorak et al (1991) which gave a weighted mean of forward flexion and extension of

56 and 18 degrees respectively and a total excursion of 84 degrees. It would appear that direct measurement tends to produce larger values than those seen in X rays studies but that both methods indicate approximately 90 degrees of lumbar flexion and extension with 20-30% of this excursion being in extension.

4.3.2 Lateral bending Values

Nearly identical values for both sides were reported in all studies. Therefore it is assumed that most authors only reported the overall excursion values. As previously reported for flexion & extension the study by Dopf et al, (1994) showed values well in excess of the weighted mean values. This confirmed the particular feature of this study as consistently reporting values in excess of the average for the other studies.

It is also noteworthy to see that the 3 studies using the Isotrak 3 Space (Buchalter et al, 1986; Hindle et al, 1990 and Russell et al, 1993) reported lower values for lateral bending compared to the studies using the CA-6000 SMA (Dopf et al, 1994; Dvorak et al, 1995, McGregor et al, 1995; Schuit et al, 1995 and Troke et al, 1996).

Close agreement between the reported weighted mean values in directly measured studies (left= 30 degrees, right= 29 degrees and overall= 60 degrees) and the in-vivo X-ray studies (left=28 degrees, right=28 degrees and overall= 56 degrees) were found for this movement. The small differences pointed, again, towards and overestimation of the values recorded by in directly measured devices compared to X-ray studies.

Despite the differences between studies it would appear that 30 degrees of lateral bending to each side can be expected.

4.3.3 Axial Rotation to the left and right.

The range of values obtained for axial rotation is large with Dopf et al, (1994), once again, reporting the highest value at 85 degrees of combined rotation and with Buchalter et al (1986) and Troke et al (1996) reporting as little as 15 and 12 degrees respectively.

Dvorak et al (1993) questioned the validity of the axial rotation values obtained using the CA-6000 SMA, due to fixation difficulties. They observed slippage of the mounting plates across the skin, and sliding of the soft tissue across the spine during axial rotation movements. These authors concluded that the measurements may have included the soft-tissue movements rather than measuring vertebral range of motion. This is a problem inherent to most non-invasive examinations of the spine. However, a new fixation system for attaching the CA 6000 SMA was developed by Troke and Moore, (1995) which might reduce this problem.

No studies were found reporting any in-vivo X-ray data for axial rotation for an accurate comparison of axial rotation values. However Dvorak et al (1993) compared their axial rotation values to data reported by Yamamoto et al (1989) who used a stereo-photogrammetry method to obtain in-vitro measurements of cadavers. They observed an average axial rotation of 10.8 degrees to each side, measuring from the sacrum to L1. Although these values do not include the rotation of T12 and are not in-vivo measurements, they are substantially (26%) different from the data presented by Dvorak et al (1993) who reported 41 degrees of rotation.

The reported values (7, 15 and 15 degrees) in the three studies using the 3 Space Isotrak (Buchalter et al, 1989; Hindle et al, 1990 and Russell et al, 1993) and the study by Troke et al 1996 using the CA-6000 SMA (12 degrees) are in close agreement with the in-vitro study

of Yamamoto et al (1989).

In conclusion, the large variety in data from the studies measuring lumbar axial rotation was more important than for the other directions. In addition, the weighted mean values differed to a large extent from the values reported from in-vitro study measurements (Yamamoto, 1989).

The weighted mean for all data was 53 degrees. However, studies using the 3Space Isotrak (Buchalter et al, 1986; Hindle et al, 1990 and Russell et al, 1993) showed closest agreement with in-vitro studies and indicated approximately 12 degrees of motion to each side in axial rotation.

4.4 Summary and Conclusion

An overview of normative data studies for 3 dimensional motion of the lumbar spine has been presented.

The following weighted mean value for 3 movements i.e. forward flexion, extension, lateral bending to left & right combined and axial rotation to left & right combined were reported:

Forward Flexion: 66 degrees
Extension: 27 degrees
Lateral bending to left and right combined: 60 degrees
Axial rotation to left and right combined: 53 degrees

The weighted mean values for 3 dimensional measurement studies overestimate the flexibility values obtained by in-vivo X-ray studies for flexion and extension. For axial rotation an even greater variation was seen, with the 3 Space Isotrak studies showing

closest agreement with an in-vitro study and indicating approximately 12 degrees of axial rotation to each side.

Forward flexion and side bending can be effectively measured by a number of systems. Axial rotation is more problematic but would appear to show greatest agreement, with in-vitro obtained values, when measured with the 3 Space Isotrak.

Normative data of lumbar spine RoM are influenced by age and gender. It is suggested that age and gender, in addition to the sort of 3 dimensional measuring system used, are the main sources of variability in the data obtained.

It is concluded that although a number of devices are available to measure lumbar motion in three dimensions, the data produced by them appear to vary more than could be expected due to differences in the nature of the subjects tested. It would seem therefore that some of these devices must have questionable validity particularly for axial rotation.

The studies using the 3 Space Isotrak showed closest agreement to Yamamoto (1986) in-vitro obtained values for axial rotation and therefore have the greatest face validity.

In this study it was decided that the 4 Isotrak studies using a 3 Space Isotrak best represent the true axial rotation values of the spine and have therefore been selected to represent the expected normal range of axial rotation i.e. 12 degrees of axial rotation to the left and 12 degrees of axial rotation to the right.

It would appear from the literature that the current best estimate of lumbar ranges of motion are:

- 93 degrees of flexion / extension overall with 66 degrees of forward flexion, 27 degrees of extension
- 60 degrees of lateral bending overall with 30 to the left and 30 to the right
- 24 degrees axial rotation overall with 12 to the left and 12 to the right.

5. Rationale, Aims and Hypotheses of the study

5.1 Rationale

Low back Pain (LBP) is the most frequent cause of activity limitation among adults in industrialised societies and leads to substantial demands on the health care system (Praemer, et al 1992). A common problem thought to follow an acute attack of low back pain is loss of normal mobility resulting in functional limitation of the patient and hence disability.

Physiotherapy is used widely in the management of acute & subacute low back pain and a high proportion of clinicians believe it to be effective (Cherkin et al, 1995). Over the last 3 decades physiotherapy has seen the development of orthopaedic manipulative therapy (OMT) as a speciality, within the profession. Its growing popularity has been illustrated by the integration of mobilisation techniques in undergraduate level programmes in the U.K. Furthermore, postgraduate courses in orthopaedic manipulative therapy are very much in demand among physiotherapists world-wide.

Orthopaedic manipulative therapy's primary aim is restoration of full normal range of motion and reduction of pain levels by using joint mobilisation (without thrusts) or joint manipulation (with thrusts) techniques. Moreover, most of the contemporary textbooks in orthopaedic manipulative physiotherapy indicate that the techniques advocated are expected to bring an immediate improvement in the patient's condition. A failure to do so would suggest that the techniques are not appropriate for the patient or perhaps have not been undertaken correctly (Grieve, 1979; Cyriax, 1984; Kaltenborn, 1993; Mulligan, 1995).

It is normal for physiotherapists to generally perform some sort of lumbar spine movement

assessment when presented with a patient complaining of low back pain. However, most clinicians will only perform a subjective assessment of a patient's movement by eye (Hindle, 1989) and documentation of improvement or non-improvement is limited to subjective interpretation by the clinician or pain related impressions given by the patient. Why is this so? The lack of suitable, easy to use measurement techniques in the clinic has deprived the physiotherapist of measurement techniques with which to optimise his assessment and consequent treatment of low back hypomobility. Furthermore, the need for versatile, easy to use and relatively non-expensive measurement tools is increasingly apparent as the demand for objective documentation of treatment effect and efficiency from private health insurance companies and health care providers is growing. In the United Kingdom, the escalating costs for back pain disability are increasing the demand for non-invasive assessments and treatment methods of back pain with proven efficacy.

The spine is a complicated three-dimensional structure and it might therefore be expected to undergo complex movements in three-dimensions. Alterations to movements, due to low back pain, may not affect the total range of motion, but may affect the manner or pattern of the movement. Therefore any measurement system for RoM should ideally measure the three-dimensional movement behaviour of the lumbar spine (Hindle et al, 1990) and should be able to do so during a range of functional activities (Rowe and White, 1996)

Despite the popularity and reporting of anecdotal success of OMT there is a paucity of valid clinical trials investigating the effects of the techniques used. However, before we can investigate the efficacy of clinical practice reliable and valid measuring tools and protocols for measuring the mobility of the lumbar spine have to be developed.

5.2 Research Aims

5.2.1 General Aims

This project aims to investigate the effects of low back pain on lumbar spinal motion during a series of gross movements and functional activities and hence contribute to the conceptual framework related to low back pain. In addition, to carry out a randomised controlled trial to determine the effects of passive mobilisation techniques on the pattern and range of movement in acute/subacute low back pain patients and hence enhance the theory and practise of orthopaedic manipulative therapy.

5.2.2 Specific Aims

- To develop a measuring system, based on an electro-magnetic measuring device (3Space Isotrak) capable of measuring 3 dimensional (3D) kinematics of the lumbar spine.
- To establish the repeatability of a new integrated attachment procedure for this new measurement system.
- To establish a normative database for 3D lumbar kinematics in 6 gross movements with which subsequent patient data could be compared.
- To establish whether or not acute/subacute low back patients have similar 3 D kinematics patterns and lumbar excursions as healthy subjects.
- To use this newly developed system to investigate the effect of a physiotherapeutic mobilisation procedure on kinematics of the lumbar spine, when applied to patients with acute/subacute mechanical low back pain.

5.3 Research Objectives

- To confirm the accuracy, and precision of the 3 Space Isotrak measuring tool.
- To develop a valid and reliable measurement system for 3D kinematics of the lumbar spine using an electromagnetic tracking device (3Space Isotrak).
- To develop appropriate testing protocols and data-analysis techniques suitable for the measurement of 3 dimensional lumbar spinal motion in:

  a. analytical (gross) movements of the spine (flexion/extension, lateral bending and axial rotation) in standing and subsequently in sitting.

  b. a series of functional activities (sitting down and rising to stand from a stool, going up and down a step, picking up a box and putting it down left and right).
- To confirm the repeatability of these measurements of spinal function.
- To use these measurements to assess lumbar spinal function in normal subjects and to establish a normal database for subsequent comparison.
- To investigate the effects of LBP on lumbar spinal function in a group of patients with acute/subacute LBP.
- To conduct a randomised clinical trial which investigates the immediate effect of a mobilisation session on lumbar spinal kinematics and pain level.
- To use the results of the clinical trial to discuss the efficacy of low velocity mobilisations on lumbar back pain and flexibility. To comment on the efficacy of mobilisation and to review the conceptual framework of orthopaedic manipulative therapy.

5.4 Null-Hypotheses

5.4.1 Healthy Subjects

A. There is no significant difference in lumbar spinal mobility between different age categories.

B. There is no significant difference in lumbar spinal mobility between healthy males and females.

C. There is no significant difference in excursion values of gross movements recorded in standing or sitting.

5.4.2 Subjects with Acute/Subacute Low Back Pain

D. There is no significant difference in primary gross movements excursion values between healthy subjects and acute/subacute LBP-patients.

E. There is no significant difference in primary movements excursion values during functional tasks between healthy subjects and acute/subacute LBP-patients.

F. There is no significant difference in coupled movements excursion values during functional tasks between healthy subjects and acute/subacute LBP-patients.

5.4.3 Effects of mobilisation techniques in acute/subacute LBP-patients

G. There is no significant difference between visual analogue scale-pain scores before and after a mobilisation treatment in 41 acute/subacute LBP-patients.

H. There is no significant difference between visual analogue scale-pain scores before and after a mobilisation treatment in acute LBP-patients (<6 weeks of pain).

I. There is no difference between visual analogue scale-pain scores before and after a mobilisation treatment in subacute LBP-patients (between 6-12 weeks of pain).

J. There is no significant difference between visual analogue scale-pain scores before and

after a mobilisation treatment in patients who received a mobilisation treatment immediately after a first measurement (intervention group).

K. There is no signifcant difference between visual analogue scale-pain scores before and after a mobilisation treatment in patients who received a mobilisation treatment after a measurement and 1/2 hour rest (delayed intervention group).

L. There is no significant difference in excursion value between the intervention and the delayed intervention group before a mobilisation treatment.

M. There were no significant differences in lumbar excursion values recorded within and between the intervention and the delayed intervention during the three test occasions.

6. Methods: Validation of the 3 Space Isotrak

6.1 Description of the 3 Space Isotrak device

The measuring transducer in this study was a "3 Space Isotrak" manufactured by Polhemus Inc., Colchester, U.S.A. This device utilises low-frequency, magnetic field technology to determine the position and orientation of a sensor in relation to a source or other specified reference frame providing a full six degrees-of-freedom measurement device. This information may be transmitted to a host computer in ASCII or BINARY format (3 Space user's manual, 1991).

Raab et al, (1979) described the technology used in this device. The 3 Space Isotrak consists of three components: a System Electronics Unit (SEU), a source module and a sensor module (Figure 6.1).

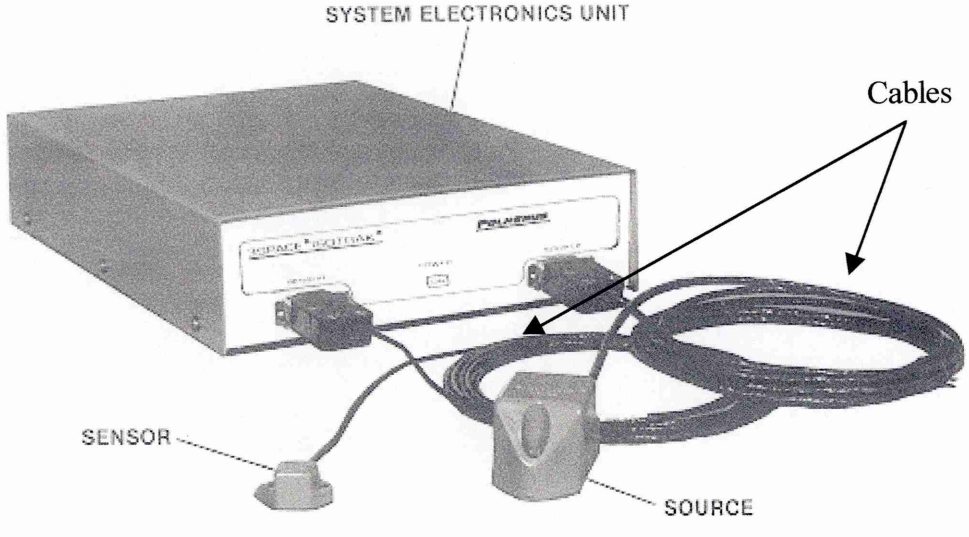


Figure 6.1 The 3 Space Isotrak system (After Polhemus 3Space User's manual)

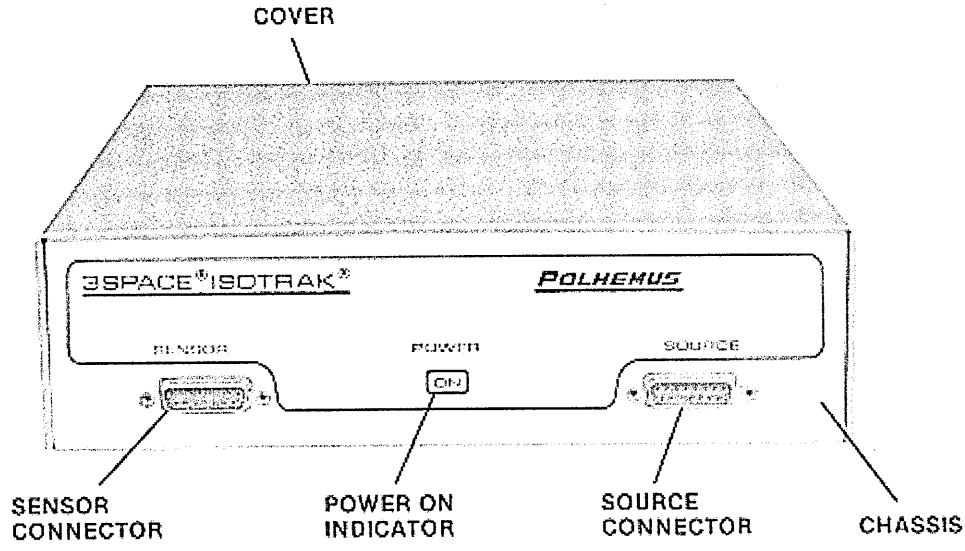


Figure 6.2 The 3 Space Isotrak System Electronics Unit

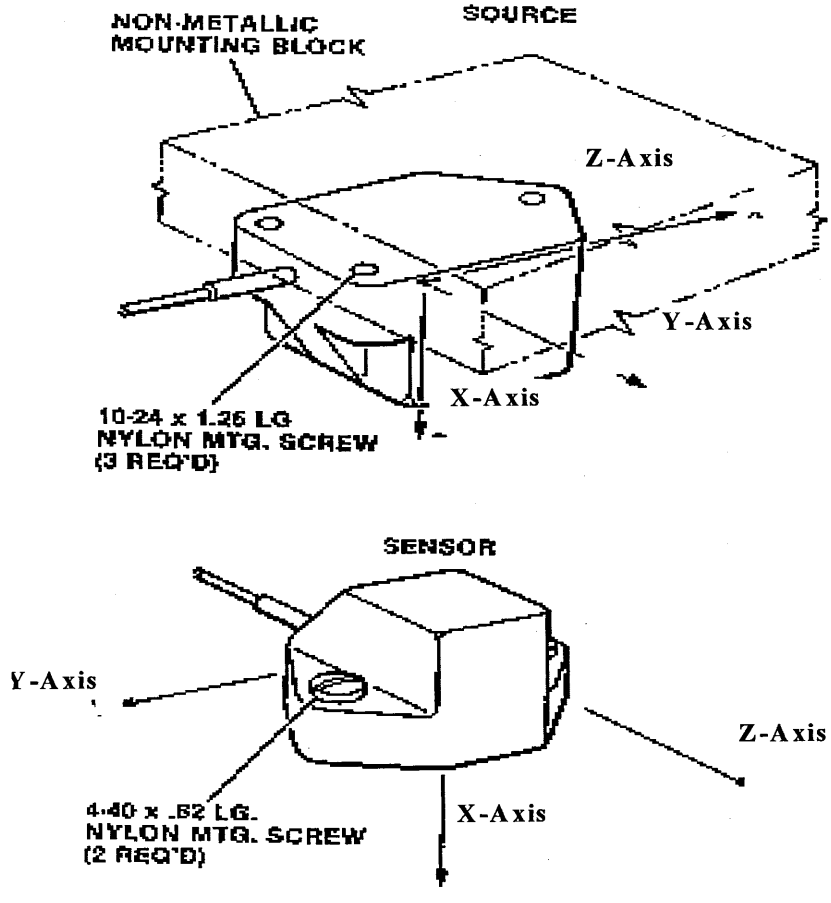


Figure 6.3 Source and sensor module with axis set orientation (After Polhemus 3Space User's manual).

Both the source and sensor are connected to the SEU (figure 6.2) by connecting cables (10m) which allow for dynamic, functional activities to be recorded. The source emits and the sensor detects low frequency magnetic fields. The SEU contains all the analogue circuitry to generate and sense the magnetic fields as well as the hardware and software to control the analogue circuitry, digitise the signals and perform the calculations to compute the position and orientation of the sensor. The SEU also allows communication with a host computer through an RS-232C serial interface port.A serial Interface board (Amplicon AT48) housed in a PC Computer (486 DX) and a purpose written Turbo Pascal computer program were used to collect the data from the SEU.

The sensor's position and orientation relative to the source (figure 6.3) were displayed by the program as 6 values: X-Translation (i.e. moving forwards & backwards), Y-Translation (i.e. moving left and right), Z-Translation (i.e. up and down), X-rotation (i.e. Lateral Bending), Y-Rotation (i.e. Flexion-Extension) and Z-Rotation (i.e. Axial Rotation) on the monitor screen (Figure 6 4). The axes and origin of the source are used to calculate these 6 values.

	Position Channels			Orientation Channels		
Sample Number	X-Translation channel (cm)	Y-Translation channel (cm)	Z-Translation channel (cm)	X-Rotation channel (degrees)	Y-Rotation channel (degrees)	Z-Rotation channel (degrees)
1	0.15	0.22	15.61	20.07	0.06	3.68
2	0.16	0.22	15.63	20.09	0.07	3.70
3	0.16	0.22	15.63	20.09	0.07	3.70
4	0.15	0.22	15.64	20.07	0.07	3.69

Figure 6.4 Representation of 3 Space Isotrak Display as it appears on the screen of a computer monitor.

A schematic representation of the three-axis magnetic-dipole source and a three-axis magnetic sensor, along with the related circuitry are shown in figure 6.5

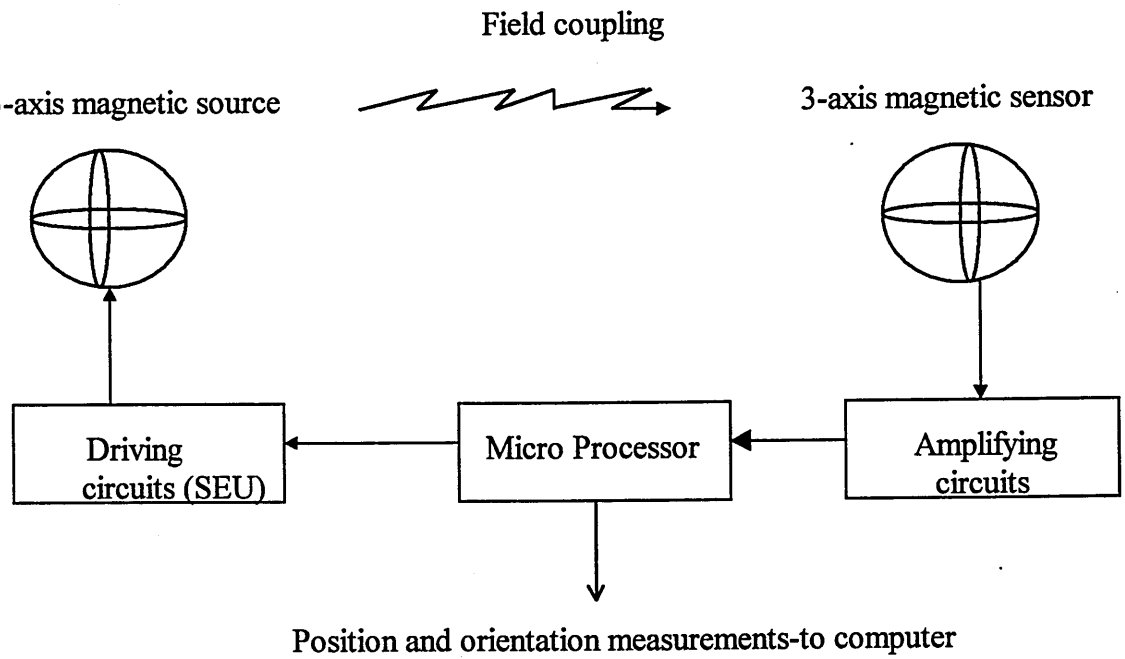


Figure 6.5 A Schematic representation of the 3 Space Isotrak System (after Raab et al, 1979).

Operation of the system is synchronous and under computer control. This system tracks the position and orientation of the sensor by determining small changes in the co-ordinates of the sensor relative to the source and then updating the previous measurements.

Kuipers (1976) invented and patented this 3 dimensional measurement position and orientation concept. The first applications, using this new technology, were initially related to a number of helmet-mounted sight (HMS) applications to measure the orientation of the helmet and consequently its wearer's line-of-sight (Raab et al, 1979).

Krieg (1979 & 1984) introduced the system for the medical and bioengineering community and suggested that it should be evaluated as a communication and feedback device for the severely disabled. Buchalter et al (1986) first used the device in preliminary trials for measuring spinal motion. An et al (1988) further suggested that the 3 Space Isotrak could have applications for measuring 3 dimensional kinematics of joints and reported the first bench validation tests. These authors found the device to be "quite accurate and easy to use" and it was suggested that "it would be a useful tool in kinesiologic research" (An et al, 1988). Subsequently Buchalter et al (1989a) gave a more detailed account of their technique and also described its application to a study of lumbar brace immobilisation of the spine (Buchalter et al, 1989b). Since then a growing number of studies, using this electro-magnetic technology, have been published in the biomedical literature (Pearcy & Hindle, (1989); Hindle et al, (1990); McGill & Kippers, (1994); Nelson et al, (1995); Rowe & White, (1996); Willems et al, (1996) and Burnett et al, (1998)).

Its ease of use, the non-invasive nature of the device and the lack of a mechanical-linkage between the two measuring points makes it one of the best-suited measuring devices for in-vivo investigations of the lumbar spine available today. However, its use so far has been limited to the laboratory research environment. No authors were identified who have used the 3 Space Isotrak to evaluate treatment techniques in a clinical setting, and hence assess its potential as an evaluation tool for clinical treatments.

6.2 Introduction to system validation

Before a measurement tool can be used in subject trials some basic properties of the tool need to be established.

First, the sampling frequency response of the instrument must be determined. If the measured dependent variable changes naturally with time, then the instrument must respond sufficiently rapidly to be able to reflect the current value of the measured variable.

It must have a frequency response that is sufficiently rapid to allow measurement of the chosen variable. If the measured variable is changing every tenth of a second and the device can only report a value once a second, then the device will not reflect the true changes in the measured variable (Durward et al, 1999).

Second: A measurement device must be precise.

Precision of an instrument refers to the "repeatability" with which a measured value can be obtained and can be considered as a random error" (Allard et al, 1995). While this definition could be thought to include all aspects of repeatability, for example repeatability over a number of days or between testers, it is usually taken to refer to the repeatability of a number of samples recorded rapidly during a small period of time. Precision is sometimes also called the "resolution" or "stability" of a system (Durward et al, 1999). In the present study the term "precision" will be used. The precision of a device records how individual samples vary from the mean of a group of samples recorded over a short period of time. If individual samples are very different from the mean then the device will lack precision.

Two almost identical methods of recording the precision of a device are found in the literature. One is the standard deviation (SD) of the data from the mean and the other is the root mean square (RMS). The standard deviation is usually found in clinical publications while the RMS value is usually found in engineering journals and manufacturer's technical sheets (Durward et al, 1999).

The standard deviation is calculated by taking the square root of the variance which is itself calculated by summing the squared differences of each sample from the mean of the group of samples and dividing by the number of samples minus one.

$$SD = \sqrt{\frac{\sum x^2 - \frac{(\sum x)^2}{n-1}}{n-1}}$$

Where n corresponds to the size of the sample or number of scores.

$\sum X^2$ is the sum of all the squares (square each score and add up all the squares).

$(\sum X)^2$ is the square of the sum (add up all the scores and square the sum).

n-1 is used in order to determine an unbiased estimate of the variance. An unbiased statistic is one that shows no systematic tendency or trend to be greater or less than the parameter of the population (Currier, 1984).

The root mean square is calculated in the same way as the SD, by summing the squared differences of each sample from the mean of the group of samples, dividing by the number of samples and then taking the square root.

$$RMS = \sqrt{\frac{\sum x^2 - \frac{(\sum x)^2}{n-1}}{n}}$$

These two formulae differ only in the use of n-1 and n in their respective denominators. When n is large there is no apparent difference between the calculated standard deviation and the RMS value.

Precision can be calculated by taking a series of measures in quick succession and then reporting their standard deviation. This will give an indication of the spread of values found in the data.

In this study the precision was calculated using 100 samples and the SD to represent the precision of the measure.

Precision may vary at different points in a measuring range. It is therefore necessary to measure the precision of the device throughout the measurement range to insure that the precision is suitable throughout the range. If some parts of the range show precision values that are not suitable then these pieces of the measuring range should be excluded.

In addition, precision may vary over time and therefore, precision tests should be repeated at different times to reflect the true precision over time.

The third basic property of a measuring tool is called "accuracy".

Accuracy is defined as the systematic differences between the reference (true) and measured values. "True" errors are fiction because exact reference values are seldom known. Accuracy can also be thought of as the systematic error (Allard et al, 1995). The convention adapted in this study will then be to use the term "reference", rather than "exact" or "true" measure.

If a measuring tool is to be used we need to know how the output of the device relates to the input. This is established by systematically observing how the measured output values from the system relate to reference input values applied to the system a process called calibration.

Some devices come pre-calibrated so that there should be a direct relationship between the input and the output such that the measured and reference values are identical. In reality

some error will occur in this response. In addition, it is always worth checking that a precalibrated instrument is responding properly as the response may change with time and the device may be damaged or faulty (Durward et al, 1999).

Positional accuracy in the present study is defined as the difference between the 3 Space Isotrak position values and the sensor's position on a calibration grid. Rotational accuracy is defined as the difference between the 3 Space Isotrak rotation values and the equivalent angle on a calibration rig (Mildne et al, 1996).

The accuracy of a device is expressed by the error reading between the measured value data and the reference value. The technique used to determine the trend in the pairs of values (measured and reference) is called regression analysis. A perfect linear regression is an analysis where an increase in one variable is followed with the same increase in the other variable and where the variables are related by the following equation:

$$Y = mX + c$$

Where:

Y is the measured or dependent variable

X is the reference or independent variable

m is a constant giving the slope of the regression line

c is a constant giving the offset of the regression line from zero (i.e. the value of Y when X is zero)

Regression calculates the best fitting line through the data so that the sum of the squares of the deviations of the measured values from the values predicted by the regression line are minimised.

Accuracy is commonly reported in terms of the distribution of error throughout the range, and by indicating the mean and maximum absolute residual error. In addition accuracy is often reported as "percentage linearity". This is calculated by dividing the maximum residual error by the measuring range (the range in the independent X variable) and expressing the ratio as a percentage (Durward et al, 1999).

6.3 Previous Validation studies performed on the 3 Space Isotrak

The 3 Space Isotrak Users manual reports an average angular accuracy of 0.85 degrees RMS within a distance of up to 0.70 m between the source and sensor and an angular precision (resolution) of 0.35 degrees RMS. The method used to establish these accuracy and precision values was not mentioned.

Pearcy and Hindle (1989) investigated the precision of the device by mounting the source and sensor securely on a solid wooden beam at approximately the same distance they would be apart (no distance mentioned) when mounted over the sacrum and the first lumbar vertebra, respectively. Data were recorded over a 10 seconds period this being repeated five times. The RMS variation for each of the three movement planes i.e. flexion/extension, lateral bend and axial rotation) for each of the five trials was less than 0.05 degrees.

The procedure was repeated while the beam, to which the source and sensor were mounted, was moved randomly in space. The random error increased slightly but the precision remained under 0.1 of a degree.

Pearcy and Hindle (1989) also assessed the accuracy of the device by comparing the data collected by the 3 Space Isotrak with values obtained by a precision optical inclinometer but limited the measuring range from 0 to 30 degrees of flexion. Four wooden wedges of different angles were measured and compared (8.67°, 18.04°, 26.85° and 34.57°).

Regression analysis showed that the relationship between the two measures was linear with the equation:

$$Y = 1.056X + 0.509$$

where, Y = true angle and X = 3 Space Isotrak reading

This equation implies that for the range of 0 to 30 degrees of flexion, the 3 Space Isotrak underestimates the angles by a factor of 1.056 or 5.6% and Pearcy and Hindle therefore adjusted their results by this factor.

McGill et al (1997) assessed the accuracy of the 3 Space Isotrak by placing a series of test objects in the electromagnetic field, in addition the drift characteristics of the 3 Space Isotrak were examined.

Angular measurements with a small wooden block in between the source and the sensor were within ± 0.05 degrees. Much larger distortions were reported with a ferrous steel disc (-1.6 degrees in the X direction, 9.35 degrees in the Y direction and 0.26 degrees in the Z direction). An aluminium block produced the same pattern of distortion as the steel disc but of a smaller magnitude.

Movement of the connecting cables connecting the sensor to the control unit produced small erroneous readings (X-direction = ± 0.04 degrees, Y-direction = ± 0.01 degrees and Z-direction = ± 0.00 degrees).

The maximum drift over an hour in the rotation signals was reported in the Z direction and was small (0.12 degrees).

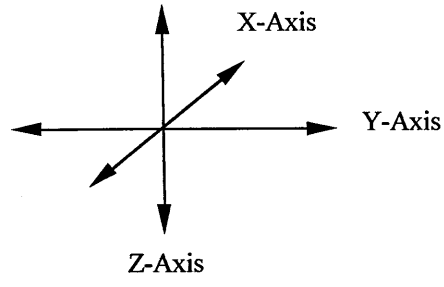
6.4 Validation experiments

6.4.1 Introduction

Although the accuracy and precision of the device had been reported to a limited degree in the literature, it was felt that none of the studies had reported the characteristics of the device in sufficient detail or with sufficient depth to conclude that the 3 Space Isotrak provided valid & reliable data. Moreover, Pearcy and Hindle (1989) used adjusted values

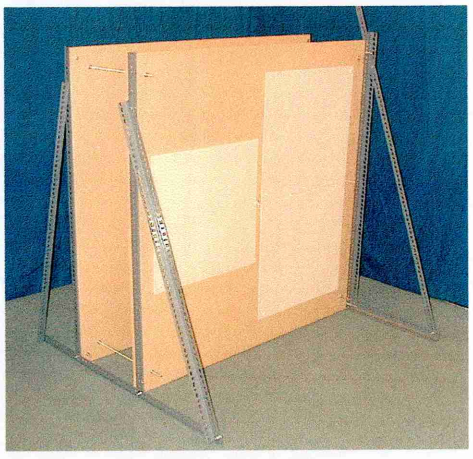
while other authors (Buchalter et al, 1989a; Burnett et al, 1998) did not mention any adjustment procedure. It was therefore decided to particularly test the characteristics of the 3 Space Isotrak device.

Data were collected in the "position and angle" mode, which outputs six values per sample. Three translations (i.e. X, Y, Z) and three rotations around an X-axis (roll), Y-axis (pitch) and, Z-axis (Yaw).



Where a movement along the X-axis is a displacement in the forward or backwards direction (X-translation). A movement along the Y-axis is a sidewards displacement (Y-translation) and a movement along the Z-axis is a displacement up and down (Z-translation). A rotatory movement around the X-axis is a Lateral Bending movement to the left or the right. A rotatory movement around the Y-axis is a flexion and extension movement and a rotatory movement around the Z-axis is an axial rotation (twisting) movement.

A calibration rig was manufactured and used in all calibration tests (Figure 6.6)



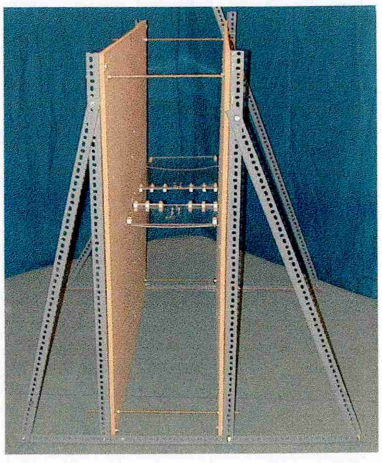


Figure 6.6 Calibration rig

This rig consisted of 2 vertically mounted Medium Density Fibre boards, reinforced at each end by steel beams to increase their stability. The wooden boards were positioned 40 cm apart and fixed in this position by 4 steel rods attached in the 4 corners. The source and sensor were bolted on 2 Plexiglas plates, which were centred around a stiff plastic axis, aligned with the source and the sensor.

Any steel was placed well away (0.5 m) from the measuring devices so as not to affect the measurements.

The following validation experiments were performed and are presented in the following sections:

6.4.2 Sampling Frequency response

6.4.3 Precision

6.4.4 Accuracy

6.4.5 Influence of different materials

6.4.6 Cross talk

6.4.7 Stability over time

6.4.8 Influence of wire movements

6.4.9 Separation and approximation of the sensor

6.4.2 Sampling Frequency Response

The sampling frequency of the 3 Space Isotrak is a complex variable, which is dependent on the baud rate of transmission, the format to report the data (Binary or ASCII) and the number of degrees of freedom reported.

In this study the baud rate was 19.2 kHz, a text format(ASCII) was used and each record contained all 6 degrees of freedom. The 3 Space Isotrak manual gives no information as to the sampling frequency that will result with these settings but simply states that a maximum sampling frequency of 60 Hz is possible. Therefore, it was necessary to establish the sampling frequency for the 3 Space Isotrak by recording samples continuously over a 20 s. period of time with the source and sensor 0.15 m apart The number of samples recorded was then divided by 20 to give the sampling frequency for the 3 Space Isotrak:

818 samples were recorded over a period of 20 seconds

$$818:20 = \underline{40.9\ \text{Hz.}}$$

The sampling frequency of 40.9 Hz used in this study is different from the frequencies reported in the available literature on the 3 Space Isotrak.

Hindle (1989) reported a sampling frequency of 10Hz during his study involving subjects performing gross movements of the lower back. Carrera et al. (1996), in a reliability study of postural sway also used a sampling frequency of 10 Hz. McGill et al. (1997) collected samples at a sampling rate of 20.5 Hz during bench test experiments with the 3 Space Isotrak and An et al (1988) reported a maximum sampling frequency of 60 Hz., thereby limiting the velocity of movement at which the 3 Space Isotrak system can accurately track a measurement. The intensity of the magnetic field is controlled by the SEU which automatically adjusts for the change in distance between the source and sensor to keep the

strength of the field reaching the sensor at a constant level. If movement of the sensor towards the source is too fast, the SEU cannot react fast enough and the signal reaching the sensor overdrives the system and an error signal is generated until compensation is achieved.

Most studies using the 3 Space Isotrak have reported static angles and hence velocity of movement and sampling frequency have been unimportant. However, one study (Burnett et al, 1998) investigated the kinematics of the lower back during high velocity activities requiring a high sampling frequency i.e. running or jumping. These authors reported a frequency of 120 samples per second.

The present study involves low velocity dynamic movements e.g. going up a step, rising to stand and static (gross) movements of flexion, extension, lateral Bending to the left and right and axial rotation to the left and right. The sampling frequency of 40.9 Hz would therefore seem adequate.

6.4.3 Angular Precision (Random Error)

The precision of the 3 Space Isotrak was evaluated by repeating a rotation of the sensor around the Y-axis on 3 different days. The calibration rig, described previously, was used in all tests.

The source and sensor were bolted on 2 Plexiglas plates (figure 6.7), which were suspended by plastic rods. The plastic rod, aligned with the sensor, functioned as the rotation axis. Data from the 3 Space Isotrak were collected with the source and sensor mounted on the plastic boards 0.15m apart. This distance was chosen because it would be the average spacing between the spinous processes of the 12^{th} thoracic vertebrae and S1. This set-up allowed a pure rotation around the Y-axis (Y-rotation) to be applied, while no movement in

the other directions occurred. The sensor and board were moved through the range of +90 to -90 at 10 degrees increments (figure 6.8).

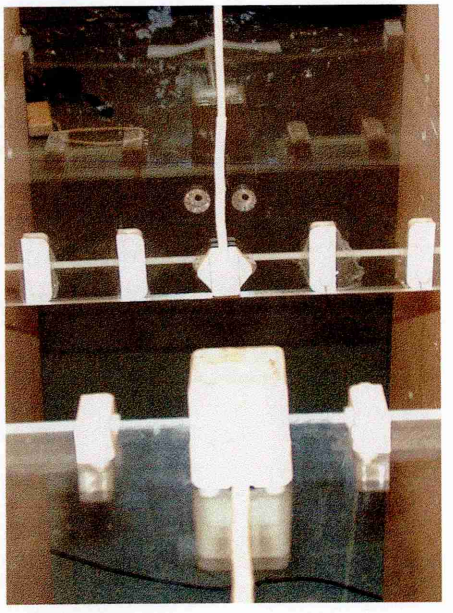


Figure 6.7 Experimental set-up

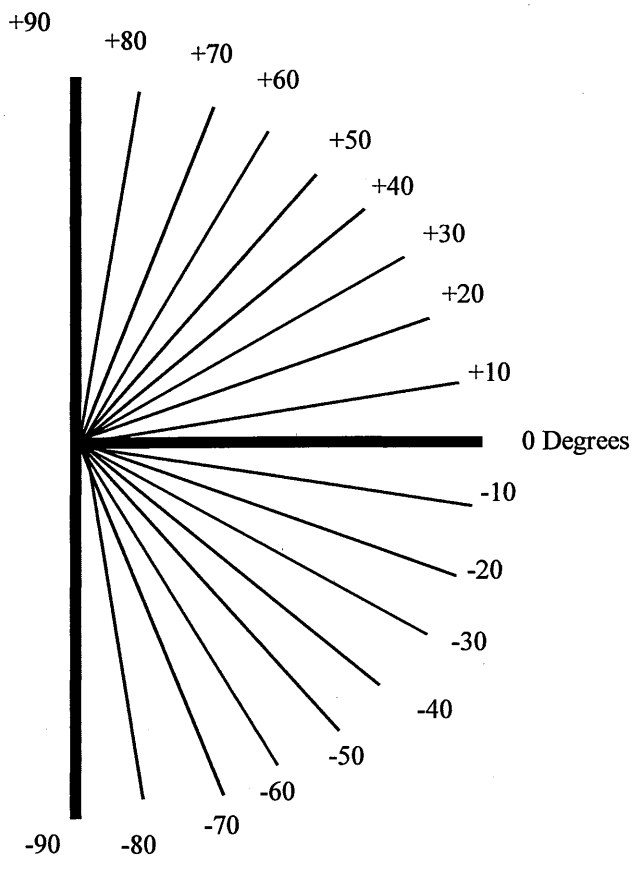


Figure 6.8 Measurement range for precision and accuracy testing

In each position values were recorded over a period of 10 seconds which gave a total of 409 samples per recording. The first one hundred values in each position were used to calculate the mean values and standard deviations. This procedure was repeated three times: on the first day (day one), on the next day (day two) and 30 days after the first day (day three).

The standard deviations of the 100 readings per position were calculated for the 19 angular positions. These are tabulated in table 6.1 for the three test days.

Measured Angle	SD Day One Degrees	SD Day Two Degrees	SD Day Three Degrees	Mean Degrees
-90.00	0.04	0.06	0.01	0.04
-80.00	0.13	0.01	0.01	0.05
-70.00	0.01	0.01	0.08	0.04
-60.00	0.04	0.04	0.01	0.03
-50.00	0.00	0.01	0.01	0.00
-40.00	0.01	0.01	0.04	0.02
-30.00	0.00	0.01	0.01	0.01
-20.00	0.01	0.02	0.05	0.03
-10.00	0.00	0.08	0.01	0.03
0.00	0.01	0.00	0.03	0.01
10.00	0.05	0.01	0.13	0.06
20.00	0.01	0.02	0.03	0.02
30.00	0.01	0.08	0.02	0.04
40.00	0.01	0.00	0.05	0.02
50.00	0.01	0.02	0.01	0.01
60.00	0.14	0.02	0.06	0.08
70.00	0.01	0.01	0.03	0.02
80.00	0.00	0.07	0.00	0.02
90.00	0.00	0.01	0.02	0.01

Table 6.1 SD of the mean for 100 recordings on three days

The highest mean SD for the 3 days was recorded at +60 degrees with 0.08 degrees and the lowest value at -50 degrees (0.00). On average over the 19 positions a mean SD of 0.03 degrees was found which would constitute the random error of the device.

The frequency with which the different values appeared between certain limits, on three different days is shown in tables 6.2, 6.3 and 6.4 as well as in figures 6.9 to 6.11

These show that 98.9%, 99.4% and 99.4% of all the deviations of the mean were between +0.25 and-0.35 of a degree on day one, two and three respectively.

Group	Frequency	Percentage
<-0.35	0	0.0
-0.35 to -0.25	1	0.1
-0.25 to -0.15	10	0.5
-0.15 to -0.5	160	8.4
-0.05 to +0.05	1567	82.5
0.5 to 0.15	152	8.0
0.15 to 0.25	10	0.5
0.25 to 0.35	0	0.0
Total	1900	100

Table 6.2: Angular Precision day one

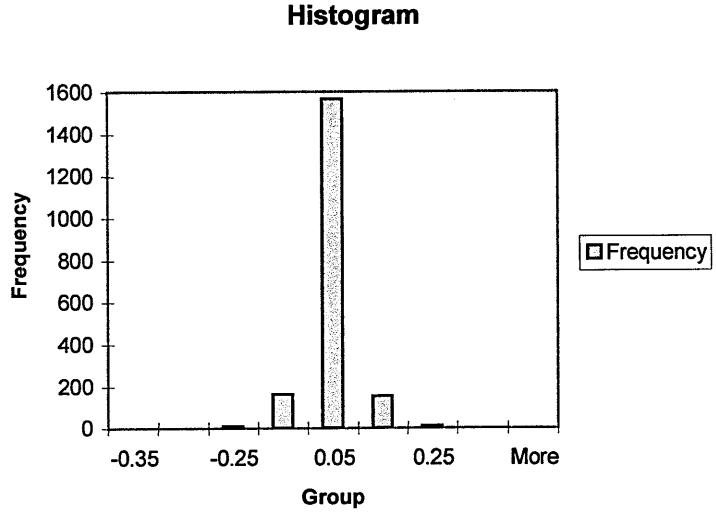


Figure 6.9: Histogram on Angular Precision day one

Group	Frequency	Percentage
<-0.35	0	0.0
-0.35 to –0.25	0	0.0
-0.25 to -0.15	5	0.3
-0.15 to -0.5	113	5.9
-0.05 to +0.05	1656	87.2
0.5 to 0.15	119	6.3
0.15 to 0.25	7	0.4
0.25 to 0.35	0	0.0
Total	1900	100

Table 6.3: Angular Precision day two

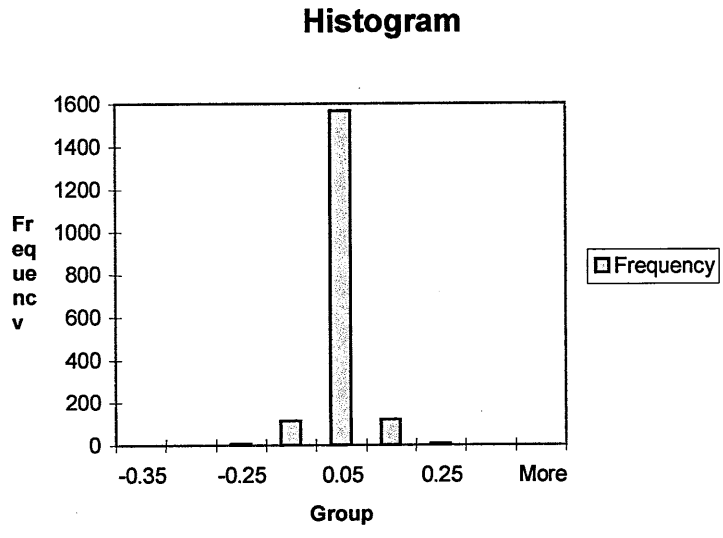


Figure 6.10 Histogram Angular Precision chart day 2

Group	Frequency	Percentage
<-0.35	0	0.0
-0.35 to -0.25	0	0.0
-0.25 to -0.15	5	0.3
-0.15 to -0.5	113	5.9
-0.05 to +0.05	1656	87.2
0.5 to 0.15	119	6.3
0.15 to 0.25	7	0.4
0.25 to 0.35	0	0.0
Total	1900	100

Table 6.4: Angular precision day three

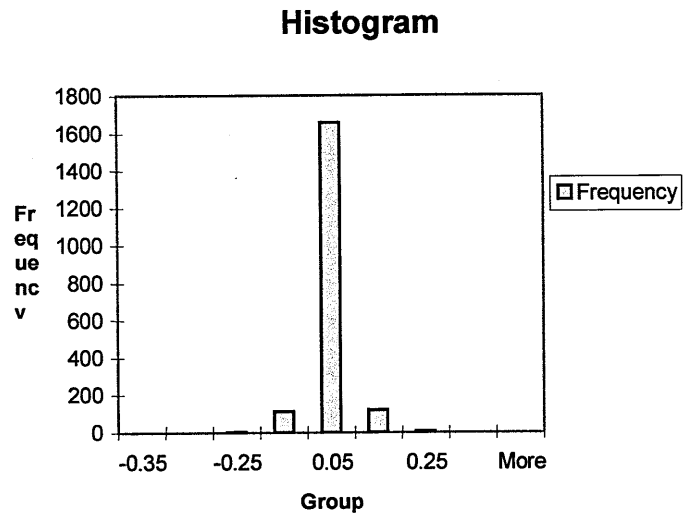


Figure 6.11 Histogram 3 Angular Precision day 3

From this experiment one can conclude that the 3 Space Isotrak demonstrated a high degree of precision (random error: 0.03 degrees) and with values close to or better than the values reported in the manufactures users manual (0.35 degrees).

The errors are symmetrical with no outliers. For a normal distribution 90% of values will fall within two standard deviations from the mean and hence we can expect 95% of values to fall within ± 0.06 degree of the mean value

It has been shown that the 3 Space Isotrak System has a rotational precision of less then one tenth of a degree (random error). In the context of this study and most clinical flexibility investigations, this level of precision values exceeds that required.

Hence this experiment has shown that the 3 Space Isotrak fulfils the criteria for precision of a clinical measurement device.

6.4.4 Angular Accuracy (systematic error)

The accuracy of the 3 Space Isotrak system was assessed in one experiment on 3 different days by comparing measured values with reference values. The reference input values were obtained by measuring an exact angle on a calibration rig and confirmed by trigonometry

The calibration rig, described previously, was used for this experiment. The same recording time (10 seconds) and data processing method as described previously was used.

Plastic grids with a nominal 5 mm spacing were attached at the outer side of the wooden boards (figure 6.12).

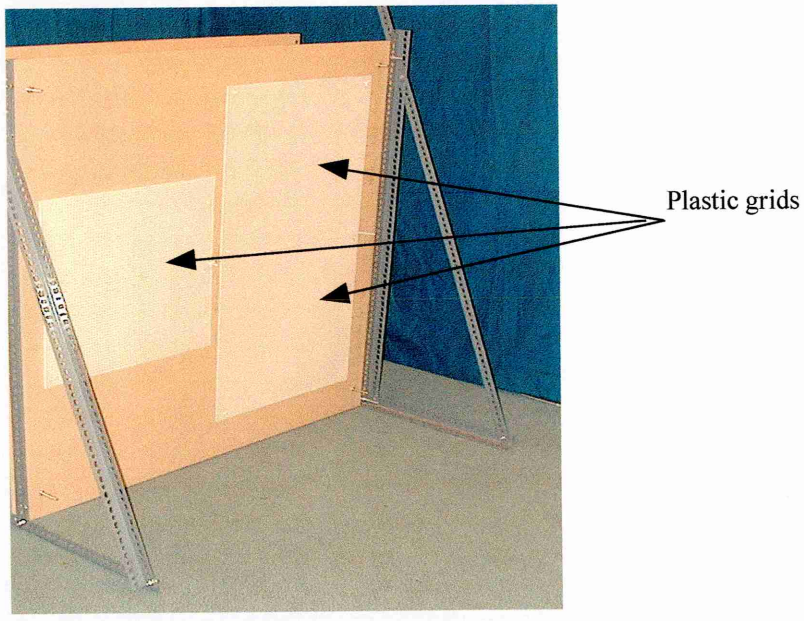


Figure 6 12 Plastic calibration grids attached to the calibration frame

This arrangement allowed for the sensor to be moved over an exact distance and over an exact number of degrees.

The output angle data on three different days as well as the associated errors are given in table 6.5 and plotted in figures 6.13 to 6.15.

The table shows that the mean error value over the three days remains less than 1.00 degree in the range 0 to ± 80 degrees. For angles exceeding ± 80 degrees the errors became increasingly larger with a maximum mean error recorded at -90 degrees (2.2 degrees).

Reference Angle °	Mean measured value (in Degrees)				Error (in Degrees)			
	Day 1	Day 2	Day 3	Mean	Day 1	Day 2	Day 3	Mean
-90.00	-89.32	-89.23	-88.85	-89.13	0.65	0.79	1.14	0.86
-80.00	-80.00	-80.35	-80.83	-80.57	0.47	0.30	0.82	0.53
-70.00	-70.20	-69.96	-70.07	-70.08	0.19	0.03	0.07	0.09
-60.00	-60.22	-60.04	-60.01	-60.09	0.17	0.04	0.00	0.07
-50.00	-50.15	-50.21	-50.06	-50.14	0.16	0.21	0.06	0.14
-40.00	-40.12	-40.37	-40.09	-40.19	0.11	0.35	0.15	0.20
-30.00	-30.20	-29.92	-30.05	-30.06	0.16	0.10	0.06	0.10
-20.00	-20.37	-20.15	-20.20	-20.24	0.37	0.15	0.25	0.25
-10.00	-10.45	-10.05	-10.41	-10.30	0.41	0.08	0.39	0.29
0.00	-0.07	0.05	0.34	0.11	0.11	0.05	0.35	0.17
10.00	10.09	10.32	10.45	10.28	0.08	0.30	0.50	0.29
20.00	20.77	20.48	20.68	20.64	0.80	0.51	0.67	0.66
30.00	30.42	30.47	30.50	30.46	0.41	0.49	0.51	0.47
40.00	40.63	40.24	40.35	40.41	0.41	0.49	0.51	0.47
50.00	50.58	50.46	50.72	50.58	0.57	0.44	0.71	0.57
60.00	60.45	60.48	60.13	60.35	0.47	0.57	0.12	0.38
70.00	70.32	70.41	70.38	70.37	0.32	0.40	0.37	0.36
80.00	80.23	80.12	80.09	80.15	0.22	0.12	0.09	0.14
90.00	88.60	87.25	87.46	87.77	1.4	2.76	2.56	2.24
				Mean	0.40	0.42	0.48	0.43
				Max.	1.4	2.76	2.56	2.24

Table 6. 5 Mean measured value and errors for three different days

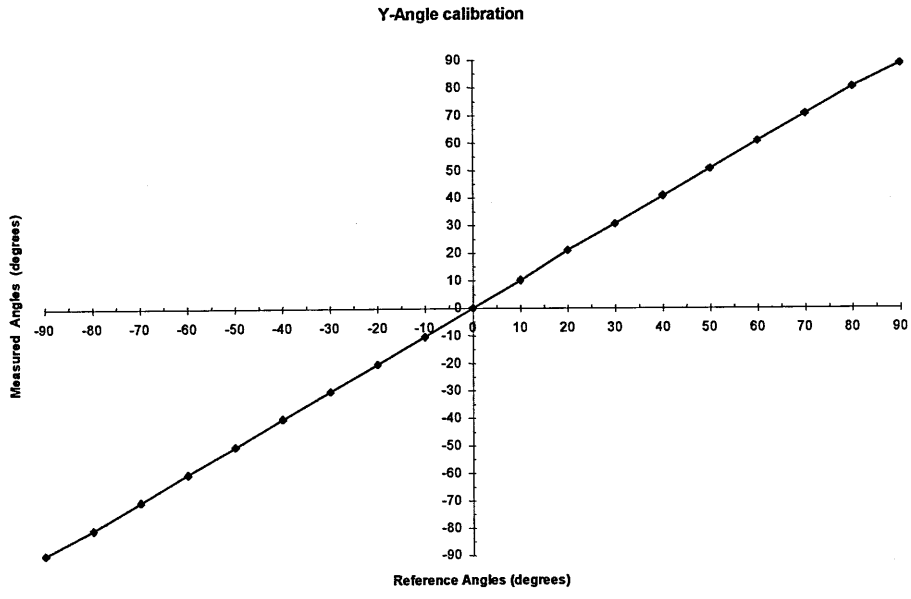


Figure 6.13 Reference angles versus measured angles (-90 to +90 degrees) on day 1

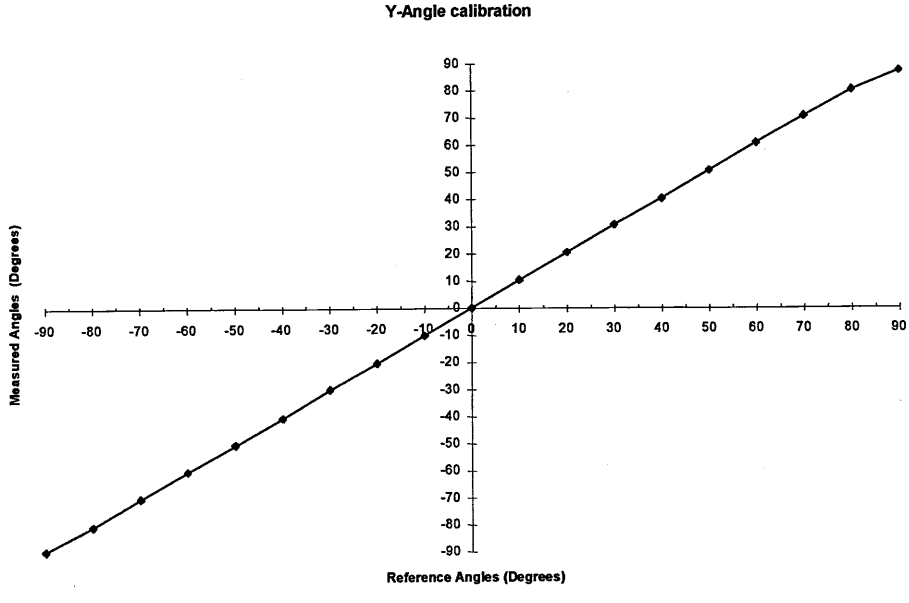


Figure 6.14 Reference angles versus measured angles (-90 to +90 degrees) on day 2.

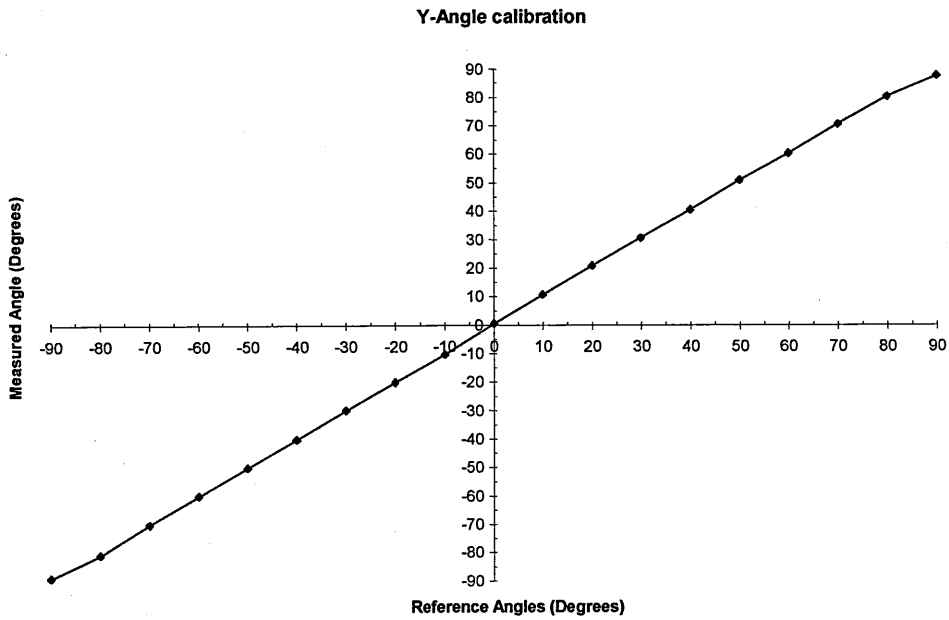


Figure 6.15 Reference angles versus measured angles (-90 to +90 degrees) on day 3

The Regression equations for the line of best fit for measurements between -90 and +90 degrees on three different days are given below:

Day one: Y= 1.001x +0.03

Day two: Y= 1.006x +0.078

Day three: Y = 0.998x +0.008

Regression Analysis showed the relationship between the measured and the reference values to be linear with a slope close to 1 and an intercept close to 0.

Plots of the residual errors are given in Figures 6.16 to 6.18 for days 1,2, and 3. These show clearly that the errors increase rapidly in the region from 80 to 90 degrees, reaching 2 to 3 degrees by 90 degrees of applied angulation. It was therefore decided to limit the working range to ± 80 degrees to give the desired level of accuracy.

Figures 6.19 to 6.21 show the response of the device in this limited range (± 80 degrees) for the three days.

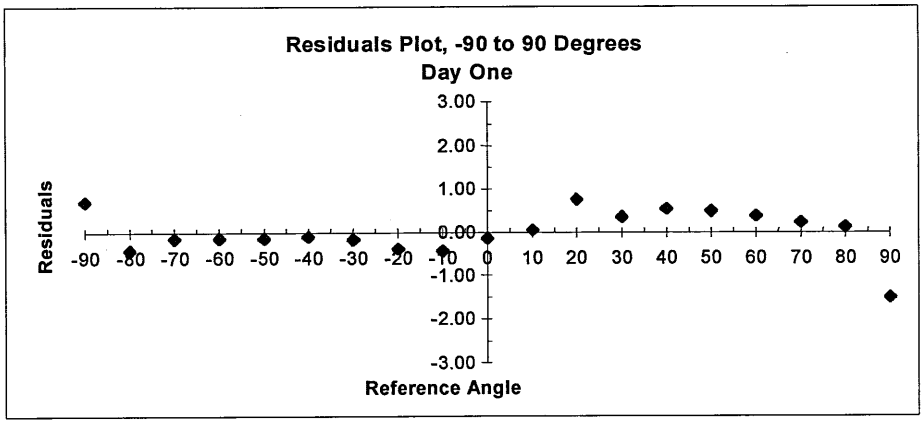


Figure 6 16 Residual plot (-90 to 90 degrees) Day 1

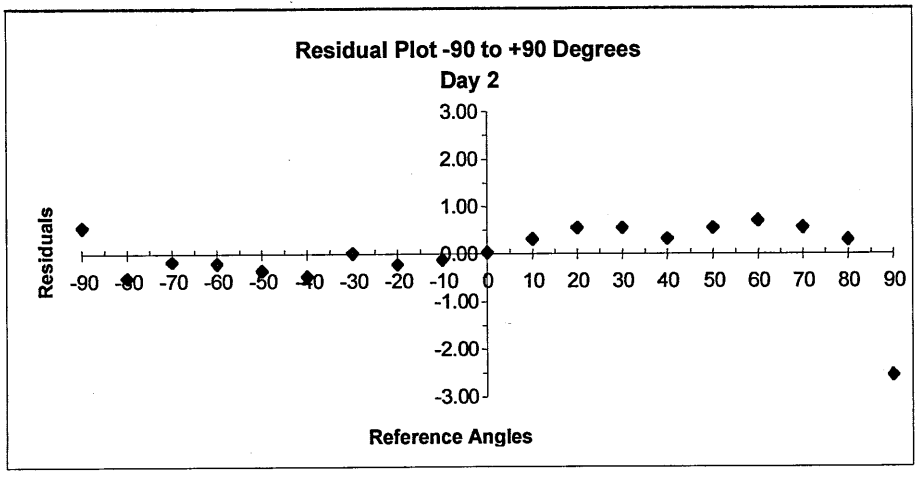


Figure 6 17 Residual plot (-90 to 90 degrees) Day 2

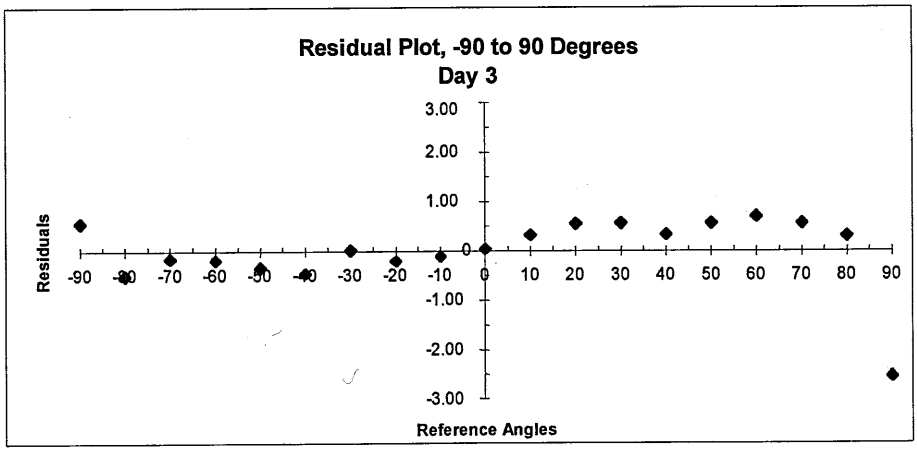


Figure 6 18 Residual plot (-90 to 90 degrees) Day 3

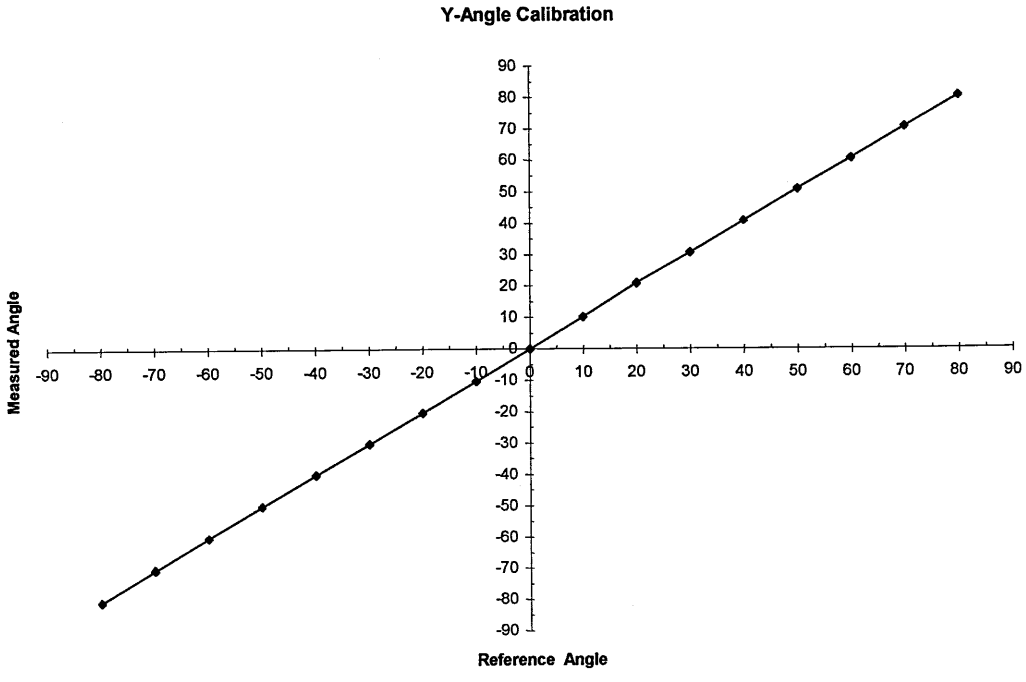


Figure 6.19 Reference angle versus measured angles (-80 to +80 degrees) on day 1

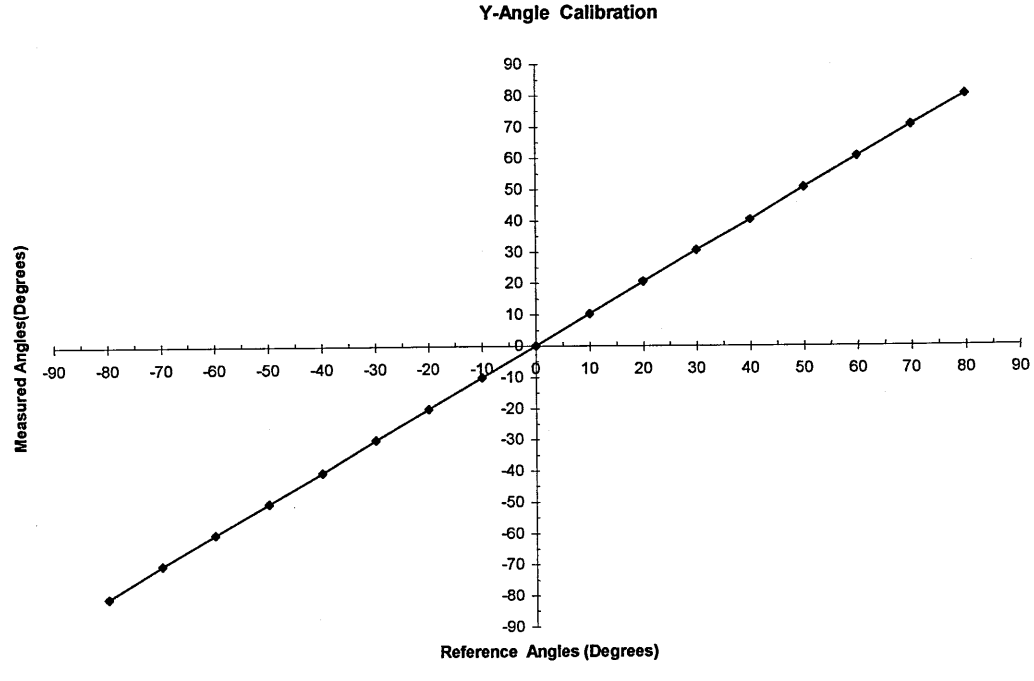


Figure 6 20 Reference angle versus measured angles (-80 to +80 degrees) on day 2

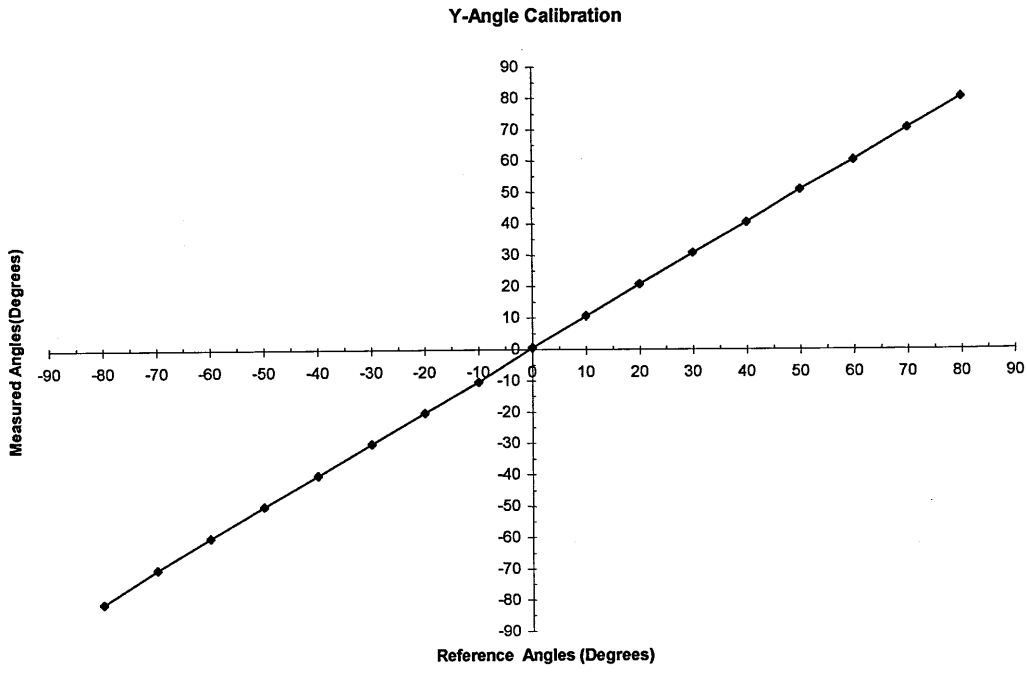


Figure 6 21 Reference angle versus measured angles (-80 to +80 degrees) on day 3

The Regression equations for the line of best fit for measurements between -80 and +80 degrees on three different days are given below:

Day one: Y=1.005x +0.07

Day two: Y= 1.004x+0.12

Day three: Y= 1.004x+0.12

Where Y is the reference angle and X is the 3 Space Isotrak measured angle.

The plots of the residual errors are given in figures 6.22-6.24.

Residual Plots of measurements between -80 to 80 degrees on 3 different days

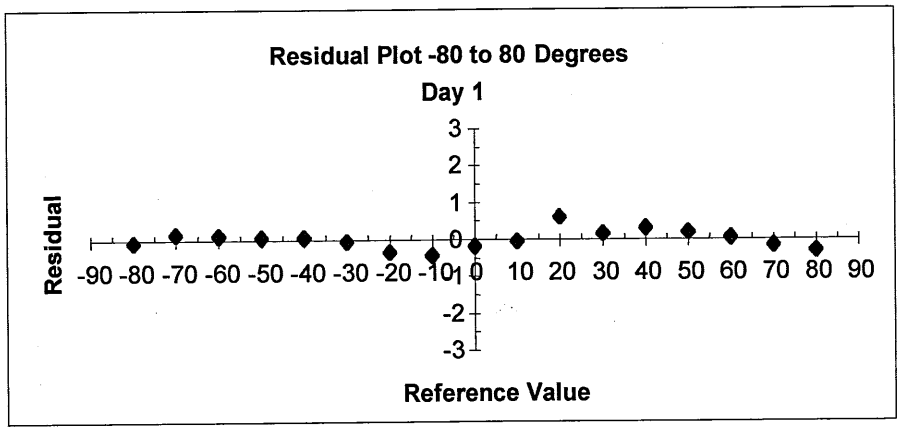


Figure 6.22 Residual plot (80 -80 degrees) Day 1.

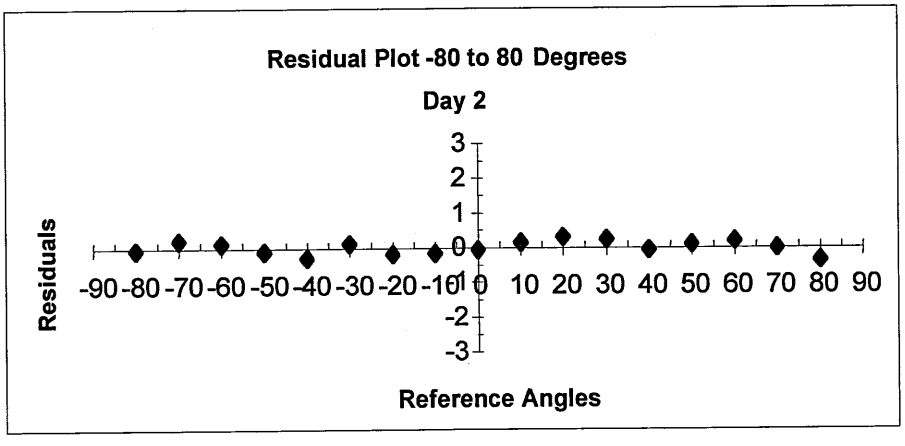


Figure 6.23 Residual plot (80-80 degrees) Day 2.

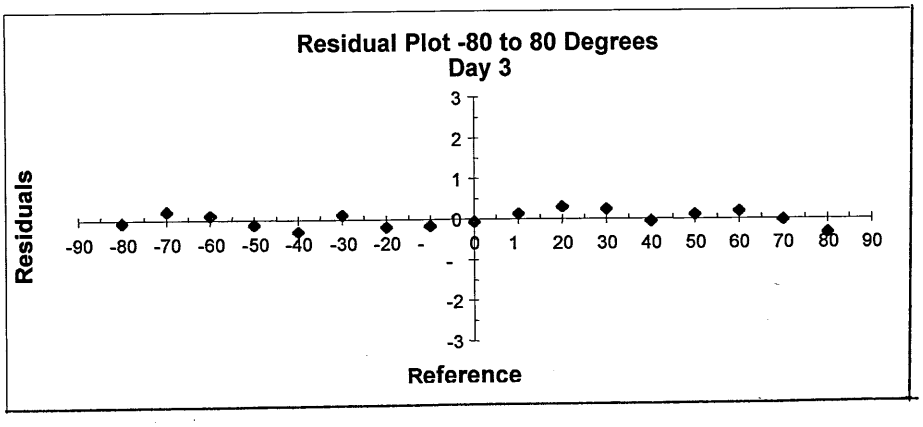


Figure 6.24 Residual plot (80-80 degrees) Day 3.

The accuracy experiments demonstrate that the 3 Space Isotrak has a mean sytematic error of 0.45 degrees in the range of ± 90 degrees with a maximum error of 2.24 degrees and a percentage linearity of 1.24 %. However when the experimental range is reduced to ± 80 degrees the mean systematic error improved to 0.32 degrees with a maximum error of 0.66 degrees and a percentage linearity of 0.38%.

These experiments have shown that the 3 Space Isotrak is an accurate device in the measuring range from ± 80 degrees but that the random errors increase rapidly beyond the 80 degrees limit until 90 degrees is reached.

Based on these conclusions it was decided to limit the range, over which to use the 3 Space Isotrak to, ± 80 degrees.

6.4.5 Influence of steel, plastic and other materials

The purpose of this series of tests was to quantify the possible decrease in accuracy when different objects made of different material were placed within the electromagnetic field between source and sensor. The clinical relevance of these experiments was related to the use of the 3 Space Isotrak over implanted materials e.g. spinal fusion plates or fixation screws for the lumbar spine.

The source and the sensor were mounted, in line on the 2 Plexiglas boards. The distance between them was 0.15 m. The Plexiglas boards were mounted within the calibration rig previously described.

The following four test objects were used:

1. A steel rod with an inside diameter of 0.04 m, an outside diameter of 0.06 m, a length of 0.20 m and a mass of 0.73 kg.

2. An aluminium rod with an inside diameter of 0.05 m and an outside diameter of 0.07 m and a length of 0.20m and a mass of 0.52 kg.

3. A small wooden block (0.4x0.8x0.1 cm) with a mass of 0.3kg.

4. A copper rod with an inside diameter of 0.05 m, an outside diameter of 0.06 m, a length of 0.20 m and a mass of 0.60 kg.

These objects were suspended on a rope and positioned in between the sensor and the source exactly 0.07m from the source. The mean and maximum errors produced in the range ±80 degrees of flexion – extension were then determined and are tabulated in table 6.6.

	Copper	Wood	Aluminium	Steel
Mean systematic error (±80 degrees)	0.61°	0.48°	8.08°	3.22°
Maximum Error	1.72°	0.95°	9.6°	6.19°

Table 6. 6 Systematic and maximum error caused by Copper, Wood, Aluminium and Iron

The angular distortions in the Y-rotation when a wooden object was placed between source and sensor were on average 0.48 of a degree with a maximum error of 0.95 of a degree. The accuracy of the 3 Space Isotrak was not substantially affected by the proximity of copper. The maximum deviation for copper from the reference position was 1.72 degrees and occurred at +80 degrees. The mean value was 0.61 degrees.

Aluminium affected the accuracy of the 3 space Isotrak substantially. On average the 3 Space Isotrak readings underestimated the reference reading in the Y-rotation by 8.08 degrees with a maximum of 9.6 degrees which occurred at +70 degrees.

Steel objects produced the same pattern of distortion as aluminium objects but on a smaller scale. On average the 3 Space Isotrak readings exceeded the reference value by 5 degrees in the positive end of the range. Only minor deviations were observed in the negative end of the range. This gave an average of 3.22 degrees over the range of 180 degrees with a maximum error of 6.10 degrees occurring at + 20 degrees.

Significant error occurred when aluminium or iron are positioned within the electromagnetic field of the 3 Space Isotrak. This is an important consideration when the device is used over implants and orthopaedic material. As a consequence of this great care was taken to avoid leading the connecting cables within the electromagnetic field of the 3 Space Isotrak

6.4.6 Influence of movement in the connecting cables.

Connecting cable movement was evaluated by simulating the motion typically seen in full flexion and extension movement i.e. lifting the cables up and down and sideways while the source and sensor module were kept at 0 degrees. This was done over a period of 10 seconds (409 readings). Movement of the connecting cables connected to the source module gave a mean reading over 10 seconds of 0.29 degrees with an SD of 0.09 degrees Movement of the connecting cables connected to the sensor module gave a mean reading of 0.23 degrees and a SD of 0.12 degrees

The precision of the 3 Space Isotrak was not substantially affected by the movement of the connecting cables. Burton and Tillotson (1988) reported erroneous readings due to the movement and pulling on the connecting cables. These authors therefore designed a different attachment system where movement in the connecting cables was reduced to a minimum. However, the results of the bench tests in the present study could not confirm the findings of Burton and Tillotson (1988).

6.4.7 Cross talk between the different recording channels

The purpose of cross talk evaluation was to investigate if changes occurred in other recording channels when the device measured a single motion with no associated movements. Cross talk between the Y-rotation channel and the five remaining recording channels i.e. XYZ-translation and XZ-rotation was evaluated on 3 days. The sensor, bolted on Plexiglas plates was moved through the range from -90 to +90 degrees in increments of 10 degrees. The axis of rotation was aligned centrally through the sensor module i.e. a pure rotation around the Y-axis was produced. The means of 100 readings for 19 positions and on 3 days was calculated and are presented in tables 6.7-6.9.

Ref Value	X-translat	Y-translat.	Z-translat.	Ref Value	X-rotation	Y-rotation	Z-rotation
-90	0.24	0.11	16.11	-90	56.35	-89.28	56.99
-80	0.29	0.13	16.07	-80	3.55	-80.43	4.18
-70	0.34	0.16	16.04	-70	1.53	-70.19	2.26
-60	0.31	0.18	15.97	-60	0.97	-60.19	1.43
-50	0.31	0.2	15.93	-50	0.03	-50.15	0.66
-40	0.31	0.16	15.86	-40	0.06	-40.11	0.3
-30	0.26	0.23	15.81	-30	0.22	-30.21	0.29
-20	0.23	-0.12	15.74	-20	0.01	-20.35	0
-10	0.18	0.15	15.64	-10	0.47	-10.51	0.01
0	0.15	0.22	15.61	0	0.1	-0.07	0.17
10	0.12	0.25	15.58	10	0.24	10.08	0.44
20	0.08	0.29	15.52	20	0.67	20.78	0.6
30	-0.01	0.18	15.53	30	0.17	30.36	0.8
40	-0.08	0.19	15.53	40	0.14	40.63	1.01
50	-0.17	0.16	15.62	50	0.65	50.59	1.61
60	-0.22	0.22	15.65	60	0.96	60.43	2.35
70	-0.27	0.22	15.73	70	2.55	70.31	3.95
80	-0.27	0.2	15.75	80	6.71	80.18	8.29
90	-0.28	0.2	15.8	90	94.87	88.6	96.65

Table 6.7 Mean values (degrees) on day one

Ref. Value	X-trans	Y-trans	Z-trans	Ref. Value	X-rotation	Y-rotation	Z-rotation
-90	0.22	-0.08	16.12	-90	64.03	-89.26	64.68
-80	0.31	-0.01	16.06	-80	2.78	-80.44	3.91
-70	0.32	-0.1	16	-70	1.76	-69.97	2.02
-60	0.31	-0.09	15.99	-60	0.87	-60.07	1.07
-50	0.28	-0.11	15.94	-50	0.51	-50.21	0.6
-40	0.24	-0.09	15.89	-40	0.18	-40.36	0.38
-30	0.22	-0.05	15.84	-30	0.06	-29.92	0.22
-20	0.21	-0.06	15.77	-20	0.12	-20.14	0.01
-10	0.17	-0.07	15.67	-10	0.06	-10.05	0.17
0	0.11	0	15.59	0	0.16	0.05	0.02
10	0.06	-0.03	15.58	10	0.01	10.28	0.33
20	-0.02	-0.04	15.57	20	0.37	20.48	0.65
30	-0.01	-0.03	15.6	30	0.46	30.46	0.94
40	-0.09	0.04	15.63	40	0.42	40.25	1.3
50	-0.14	0.01	15.66	50	0.97	50.45	1.88
60	-0.18	0.01	15.7	60	1.66	60.38	2.78
70	-0.25	-0.02	15.74	70	3.42	70.4	4.52
80	-0.3	0	15.78	80	7.33	80.12	8.71
90	-0.3	-0.02	15.8	90	32.85	87.25	34.2

Table 6.8 Mean values (degrees) on day two

Ref. Value	x-trans	y-trans	z-trans	Ref. Value	x-rotation	y-rotation	z-rotation
-90	0.24	0.14	16.1	-90	31.12	-88.86	32.1
-80	0.21	0.09	16.05	-80	3.92	-80.84	4.41
-70	0.28	0.2	16.01	-70	1.88	-70.12	2.27
-60	0.31	0.21	15.97	-60	0.71	-60.02	1.18
-50	0.28	0.19	15.93	-50	0.36	-50.05	0.44
-40	0.23	0.05	15.86	-40	0.37	-40.06	0.61
-30	0.2	0.06	15.8	-30	0.19	-30.04	0.22
-20	0.17	0.01	15.73	-20	0.29	-20.23	0.02
-10	0.11	0.04	15.67	-10	0.15	-10.4	0.07
0	0.14	0.04	15.61	0	0.08	0.36	0.21
10	0.07	0.03	15.56	10	-0.21	10.36	0.4
20	-0.02	0.06	15.55	20	-0.08	20.66	0.45
30	-0.05	0.04	15.54	30	0.27	30.48	0.93
40	-0.14	0.06	15.61	40	0.49	40.38	0.85
50	-0.19	0.11	15.66	50	0.69	50.72	1.57
60	-0.29	0.11	15.7	60	1.38	60.17	2.43
70	-0.27	0.08	15.74	70	3.23	70.4	4.22
80	-0.34	0.09	15.76	80	6.64	80.09	7.99
90	-0.31	0.06	15.81	90	34.45	87.44	35.71

Table 6.9 Mean values (degrees) on day three

No important clinically relevant changes were observed in the translation channels over the measuring range during any of the 3 days.

However an important cross talk was observed in the X and Z-rotation channels on all three measurements days. These channels began to show large errors when the sensor was rotated beyond ± 70 degrees (figure 6.25-6.27).

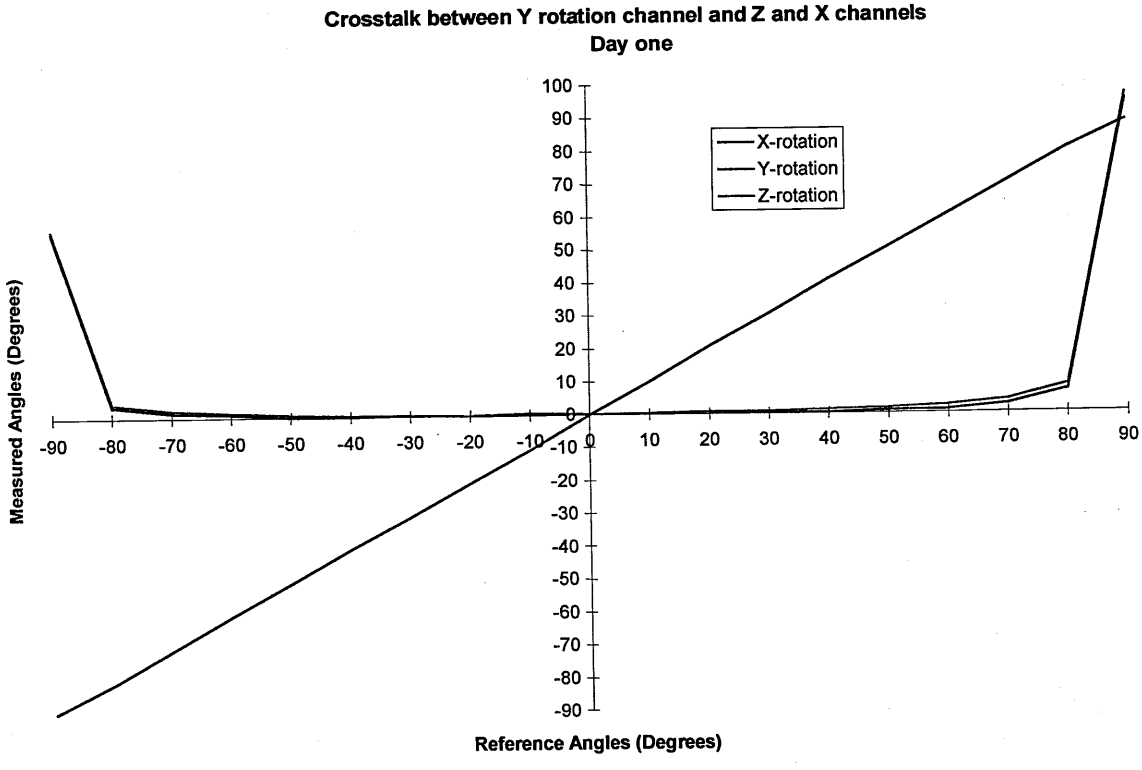


Figure 6.25 Cross talk between rotation channels during day one

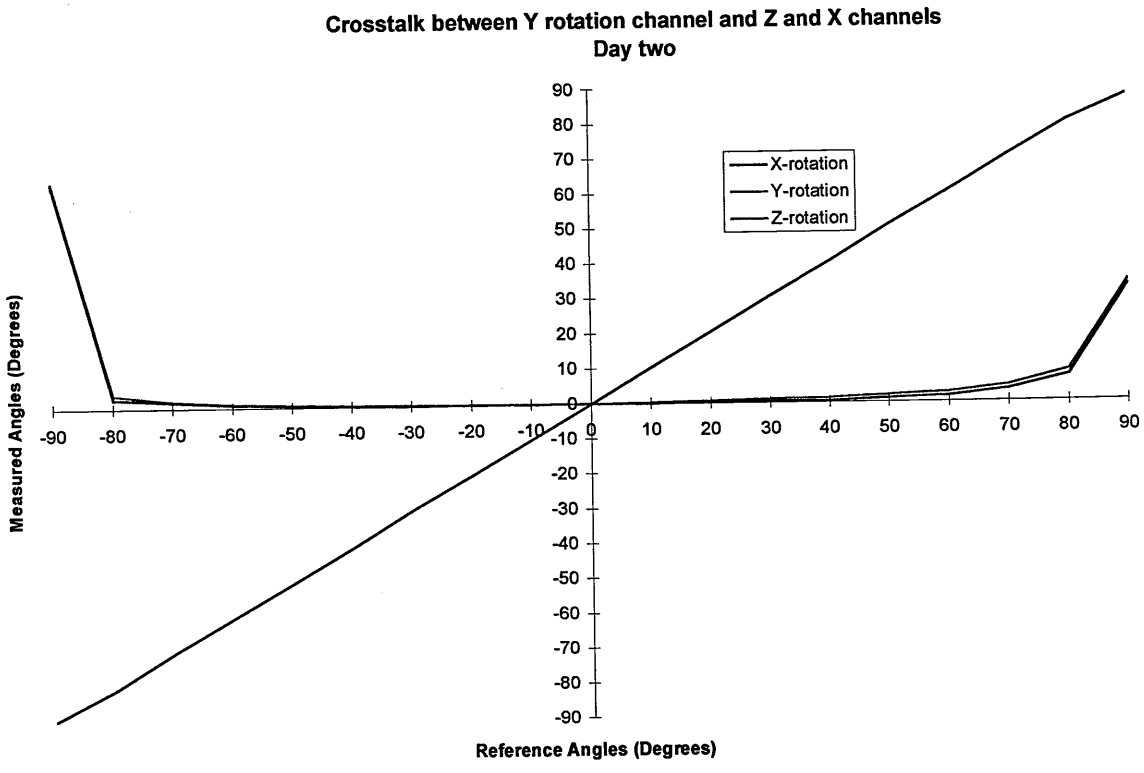


Figure 6.26 Cross talk between rotation channels during day two

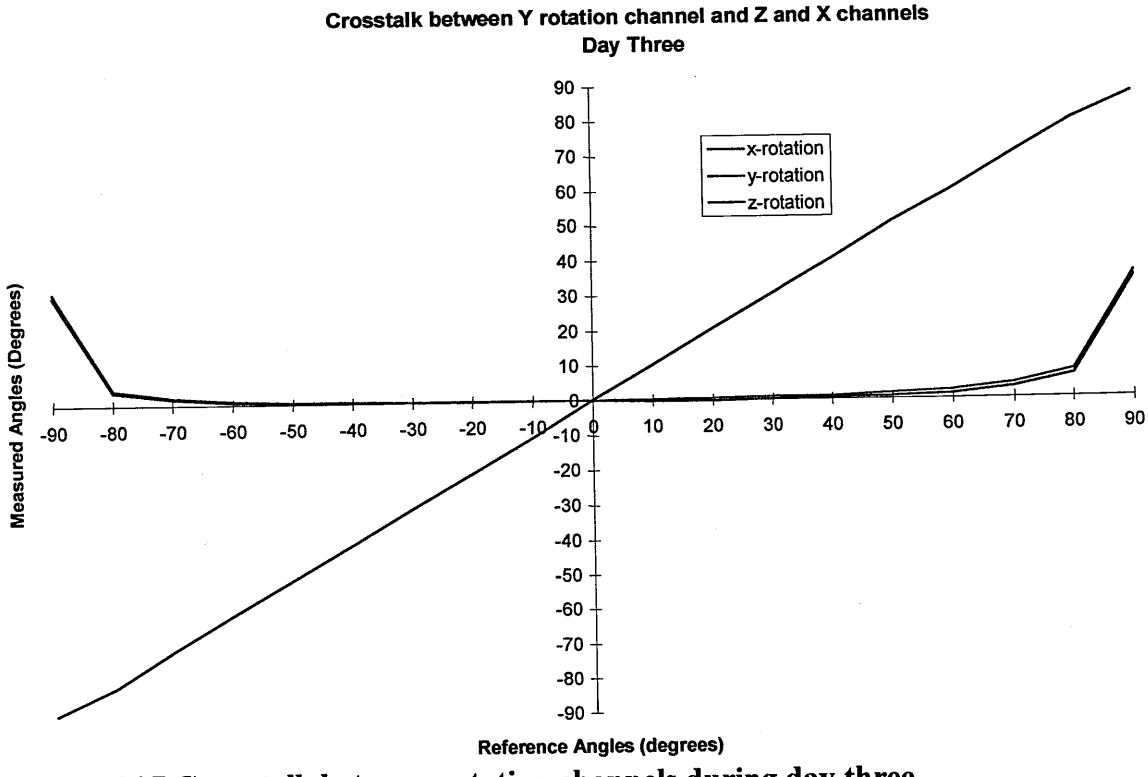


Figure 6.27 Cross talk between rotation channels during day three

6.5 Summary of the 3 Space Isotrak Validation

Accuracy experiments showed that the operational range of the 3 Space Isotrak is limited to ±80 degrees. Further, the cross talk experiments showed that errors readings were occurring in excess of 2 degrees beyond ±70 degrees which further reduces the operational RoM of the Isotrak to 140 degrees. McGill et al (1997) recently reported the same observations and recommended that one could assign the axis with the largest expected RoM to be the first recording channel to avoid cross talk between the rotation channels. This is especially important if one of the rotation angles approaches 90 degrees and it is not the first one in the sequence. McGill also reported paradoxical rotations in the other two rotation axes. Pearcy and Hindle (1989) reported that the accuracy and precision measurement in each plane were not affected by rotations in other planes. No other reports on cross talk were found in the literature.

Once the working range of the device is limited to ± 70 degrees the 3 Space Isotrak has been shown to have a high degree of accuracy and precision.

The magnitude of the errors in the ± 70 degrees operation range is well within the clinical relevant range used in physiotherapy measurements and therefore it would not be necessary to apply a correction factor to the readings.

For spinal measurements the device would seem highly suitable provided care is taken when using the device over implants where aluminium or steel is involved

7. Methods: Experimental Design and Subject Recruitment

This chapter outlines the experimental design of the healthy subjects study and randomised controlled trial and identifies the populations and samples used in both studies.

7.1 Healthy Subjects-Design

7.1.1 Introduction

Several authors have reported variations in lumbar spinal motion with age, gender, mass and height (Batti'e et al, 1987; Burton, (1987); Hindle et al (1990), Russell et al (1993).) In order to create a database for comparison, a sample representing the Scottish population, should, ideally, have a spread of age, gender, mass and height. However, it is difficult to control for all of these 4 variables within a sample of 100 subjects. Therefore a database of healthy subjects controlled for age and gender but allowing normal variations for height and weight was chosen.

7.1.2 Design

One hundred volunteers were recruited in 2 groups: 50 females and 50 males. Each gender group was further split into 5 age cohorts i.e. 20-29, 30-39, 40-41, 50-59 and 60+.

The subjects were measured performing 20 functional test-movements (see chapter 8, protocol). All healthy subjects were tested in the afternoon in order to avoid diurnal influences (Dvorak, 1995, Wing et al, 1992)

7.1.3 Recruitment, Ethics, Exclusion criteria

Volunteers from the following populations were asked to participate in the trial.

(1) Healthy students aged 20-30 from Edinburgh University.

(2) Healthy students aged 20-30 from Queen Margaret University College, Edinburgh

(3) Healthy subjects aged 30-60+ from members of staff and maintenance personnel of

Queen Margaret University College, Edinburgh

(4) Healthy subjects aged over 60, from members of an 50+ "exercise group" held at the physiotherapy department of the Western General Hospital, Edinburgh.

(5) Healthy subjects aged 60+ from members of an 60+ "exercise group" held at Leith community centre.

Ethical approval was applied for and granted from Queen Margaret University College, Ethics Committee for the testing protocols and access to all healthy subjects.

Coding procedures, in accordance with the data protection act (1984), were used so that only the principal investigator knew which results pertained to which subject.

Exclusion criteria included:- any treatment or consultation for low back pain in the last 6 months

- pregnancy.

7.2 Randomised Controlled Trial-Design

7.2.1 Introduction

In order to test the effectiveness of an orthopaedic manipulative therapy intervention on lumbar spinal mobility and pain, a blocked randomised controlled trial was carried out. Randomised controlled trials (RCT) are widely accepted as the optimal experimental methodology for obtaining evidence on the effectiveness of an intervention (Begg et al, 1996).

7.2.2 Design

The patients were considered for inclusion by the treating physiotherapist after an initial assessment session. The treating physiotherapist made sure the patient did not present any of the pre-set exclusion criteria (see.7.2.3) and subsequently decided whether or not mobilisation techniques were indicated as an appropriate treatment option. If the subject

could be included in the trial i.e. was likely to receive mobilisation treatment, then the treating physiotherapist informed the patient about the trial. An information sheet was handed out to the patient and at least 48 h before the next appointment in order to consider inclusion in the trial. It was emphasised for the patient that the trial would not affect or alter the treatment procedure in any way and that all the measurements related to the trial would be for the first treatment session only. Subsequent treatment sessions would not involve measurements related to the trial.

Patients, meeting the inclusion criteria were randomly assigned, using blocked randomisation techniques, to either an intervention group or to a delayed intervention group.

Each physiotherapist used an envelope containing 4 separate sheets of paper, 2 sheets marked "delayed intervention group" and 2 sheets marked "intervention group". The physiotherapists used the envelope for 4 patients whereafter 4 new, marked, sheets of paper were put in the envelop. By using this "block of 4" randomisation design it was possible to end the trial at any time without having a large discrepancy in numbers between the 2 groups (intervention and delayed intervention) of patients.

After the randomisation procedure patients were given a new appointment time in accordance to the group allocation. The time of intervention for the patients differed depending on whether they were allocated to an intervention or delayed intervention group, but was mainly during the afternoon.

Patients were asked to inform the principal investigator before their next appointment if they subsequently decided not to be considered for inclusion in the trial. If they withdrew before the initial appointment time then the measurement sessions would be cancelled, however the scheduled treatment time would be kept. Six patients, initially scheduled for inclusion in the trial, subsequently withdrew from the trial.

The patients were asked to formally consent to inclusion in the trial at the beginning of the first measurement session and none withdrew at this point.

A pure control group (no intervention) was not used as withholding of treatment in LBP patients was considered ethically unacceptable. Therefore a design was chosen in which treatment was delayed but not withheld.

All patients in the trial received the same treatment i.e. lumbar mobilisation. However the patients allocated to the group called "Delayed Intervention" would receive this treatment delayed by 1 hour whereas the group called "Intervention" would receive the treatment immediately after the first measurement. Measurements and intervention were performed in half hour blocks with the complete procedure lasting 2.5 hours

The sequence of measurements and intervention is illustrated in Table 7 1.

	Randomised Controlled Trial Design				
Intervention group	Measurement 1	**Intervention**	Measurement 2	Rest	Measurement 3
Dealyed intervention group	Measurement 1	Rest	Measurement 2	**Intervention**	Measurement 3

Table 7.1 Sequence of measurements and intervention for intervention and delayed intervention groups.

This design of RCT also provides information on the delayed treatment effect of a mobilisation technique. This can be assessed by using the two measurements recorded for the intervention group following the intervention and separated by a period of rest.

On arrival at the clinic, patients were met by the principal investigator. The purpose and testing procedures of the trial were restated and the patients were asked if there were any further queries. Patients were then asked to give informed consent. Subsequently they

completed pain (Visual Analogue Scale) and functional ability (Roland Morris) questionnaires, their height and weight were recorded and the timescale for the session (2.5 h.) was reiterated.

All patients then performed 20 functional tests. The lumbar motion used by the patients and measured using the 3 Space Isotrak system was recorded for each test. Details of the testing protocol are presented in chapter 8.

Thereafter patients allocated to the control group were asked to rest for half an hour quietly at a place of their choice which could be the waiting area, the treatment room or going for a stroll to the cafeteria. Patients allocated to the intervention group were seen by the treating physiotherapist in order to receive their first treatment.

The principal investigator left the treatment cubicle before the treating physiotherapist came in and was unaware of the treatment given. After the treatment session a new series of measurements was taken and the "intervention group " patients then had 1/2 h. rest. A third measurement series was taken after the rest period.

Patients in the delayed intervention group, who rested immediately after the first measurement, got remeasured after the 1/2 h. rest and subsequently received their treatment. Immediately after the treatment they were measured for the third time and finished the trial there.

A summary of the design of the randomised control trial is illustrated in figure 7.1

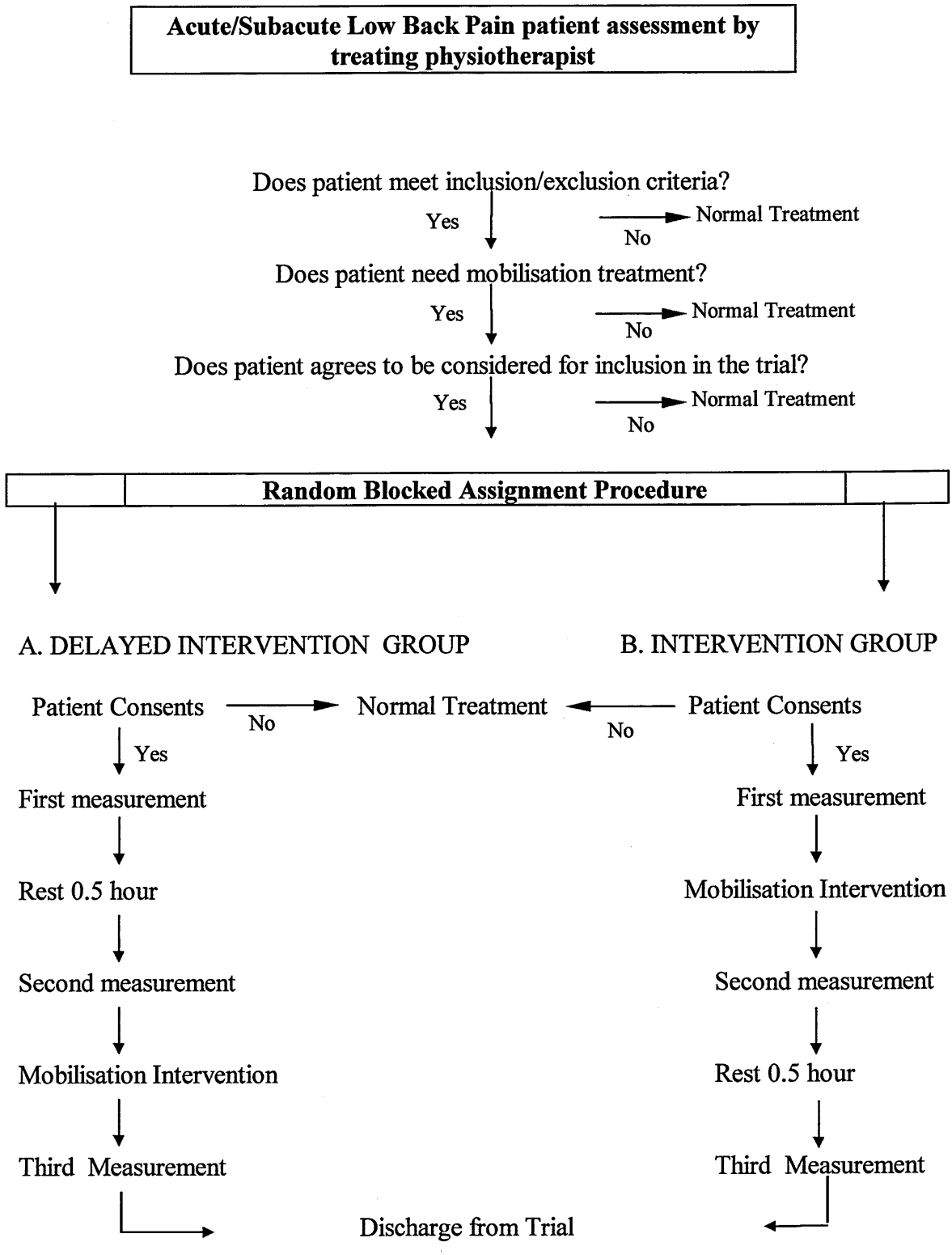


Figure 7.1 Experimental design

7.2.3 Recruitment, Ethics, Selection, Inclusion and Exclusion criteria

Suitable patients were initially identified from the outpatient waiting list at the outpatient department of the Western General Hospital, Edinburgh by the principal investigator.

Referrals by General Practitioners and Consultants where a diagnosis of acute/subacute low back pain was written were short-listed for assessment by one of the six participating physiotherapists. The patients were booked in for treatment by the departments receptionist.

Ethical approval was applied for and granted from the Lothian Research Ethics Committee for the testing protocols and access to all patients.

Coding procedures, in accordance with the data protection act (1984), were used so that only the principal investigator knew which results pertained to which subject.

A written sheet was given to all patients prior to the first treatment session, detailing the nature of the trial and the measurement sessions involved. (Appendix.7.1.). Further verbal clarification was offered to the patient before the first measurement took place.

The patient was not asked to consent to the trial for at least 48 hours after the information about the trial was given to them (Appendix.7.2.).

The principal statements of the consent form included:

- Patients could withdraw from the trial at any stage without penalty.
- Patients understood the nature of the trial and consented to participating as a subject.

The patients were recruited between September 1998 and April 1999. A total of 180 patients with a LBP referral were assessed by 6 participating physiotherapists. Of these 41 patients were enrolled in the trial.

Inclusion/ Exclusion Criteria

Each participating physiotherapist was asked to apply the general inclusion/exclusion criteria which apply for this study, together with the following:

1. Age between 20 and 80 years of age
2. Subjects must have suffered from LBP for no more than 12 weeks in each attack.
3. Subjects should not be involved in any form of litigation.

The physiotherapists were also asked to decide on the appropriateness of mobilisation as a treatment for this patient. As different physiotherapists, trained in different schools, apply different systems of mobilisation the specific criteria for this judgement were left to the treating physiotherapist. This pragmatic approach was chosen as the study aimed to reflect the real live situation as closely as possible.

In summary patients were included in the trial if they had acute or subacute low back pain, with hypomobility symptoms which the treating physiotherapist considered suitable for treatment using mobilisation. Forty-one subjects out of 180 met these requirements.

8. Methods: Testing Protocol

8.1 Description of a new alignment procedure for the 3 Space Isotrak

In order to measure lumbar spinal motion the 3 Space Isotrak must be attached to the dorsal surface of the lumbar region and this presents some difficulties.

When attached to the lumbar region, with the source located on the pelvis and the sensor over the spinous process of T12, the lumbar lordosis of the low back prevents the source and sensor from pointing straight to each other (Figure 8.1). Hence the axes of the source and sensor are not aligned to the body's neutral position.

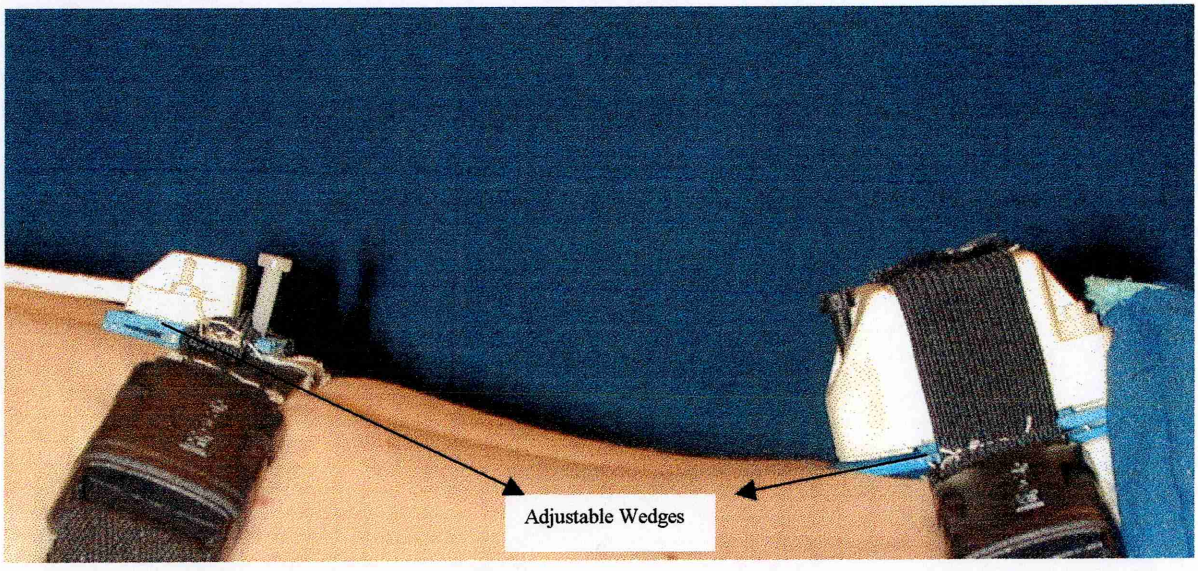


Figure 8.1 Source and Sensor module attached to the lumbar region (non-aligned)

An alignment or zeroing procedure is therefore required to place the axes of the source and sensor parallel to the anatomical planes of the body. The 3 Space Isotrak software provides an alignment procedure which allows the user to define an origin and reference plane from which the X,Y,Z measurements are taken (Three Space Isotrak, Users Manual, 1991). Alignment data

consists of the co-ordinates, in the source reference frame, of three non-collinear points in space that are used to define the "alignment reference frame".

Rowe and White, (1996) reported difficulties with this alignment procedure, performed under computer control, in that the device failed to respond to the alignment command correctly. Initially, attempts were made to reset the origin of the reference plane so that it occurred midway between the source and the sensor and to align the axes so that they corresponded to the anatomical axes of the lumbar spine. However, Rowe & White (1996) reported that resetting of the origin of the axes caused a simultaneous three-dimensional rotation of the axes set and similarly that resetting of the orientation of the axis set led to a shift in position of the origin. It was not possible therefore to simultaneously align both the angular measurements and the translational measurements to the anatomical axes and nominal centre of the lumbar spine

Consequently, it was necessary to develop a more reliable, robust and easy to perform alignment procedure which could be performed independently of computer control.

The source and sensor were mounted on separate adjustable plastic wedges (figure 8.1) which allowed the clinician to alter the altitude of the source and sensor so that they are always facing each other and are parallel when attached to the lumbar spine.

The following protocol was followed:

First the source module was attached over the sacrum (using the attachment procedure described later in section 8.2). Then the sensor was attached in line with the source to Th12 (figure 8.2). Attaching the source and sensor in line brought the Y-Translation (Translation to the left or right of the spine), X-rotation (Sidebending) and Z-rotation (Axial Rotation) channels to zero which could be verified from the computer display.

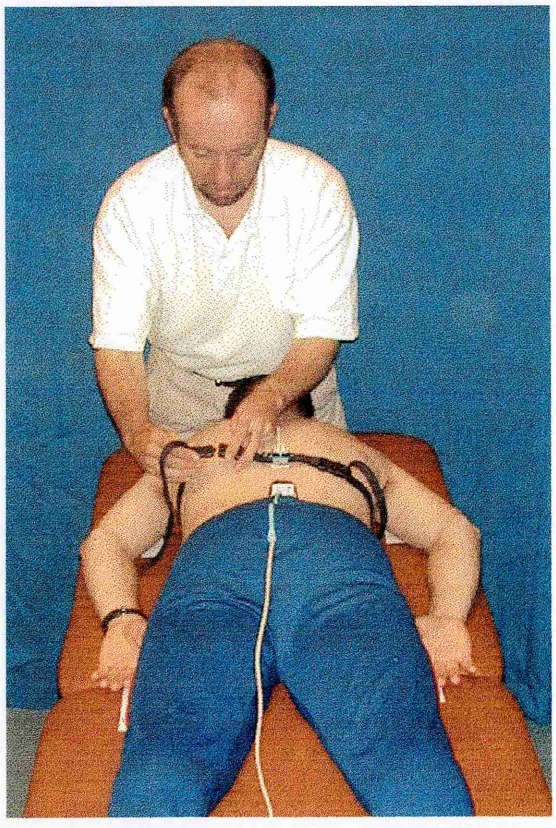


Figure 8.2 Attaching and aligning the source and sensor module

Second, the source module was adjusted by opening the adjustable pitch wedge until the source pointed straight at the sensor (figure 8.3). This procedure brought the X-translation channel (Anterior-Posterior translation) to zero.

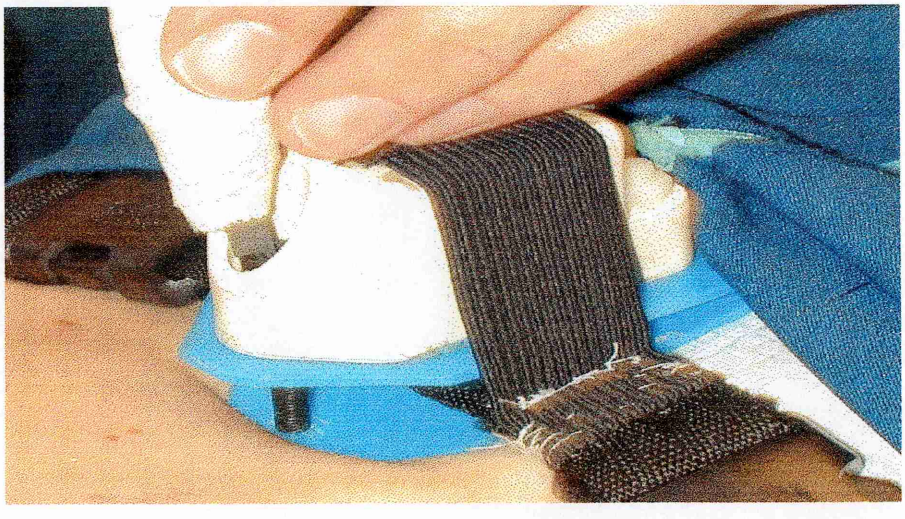


Figure 8.3 Opening the wedge on the source module

Finally the sensor module was adjusted by opening the adjustable wedge on which it was mounted (figure 8.4), until it pointed directly at the source and hence bringing the Y-rotation

(flexion-extension) channel to zero. The Z- translation channel was not zeroed as the source and sensor were always a certain distance apart (dependent on the distance between Th12 and S1).

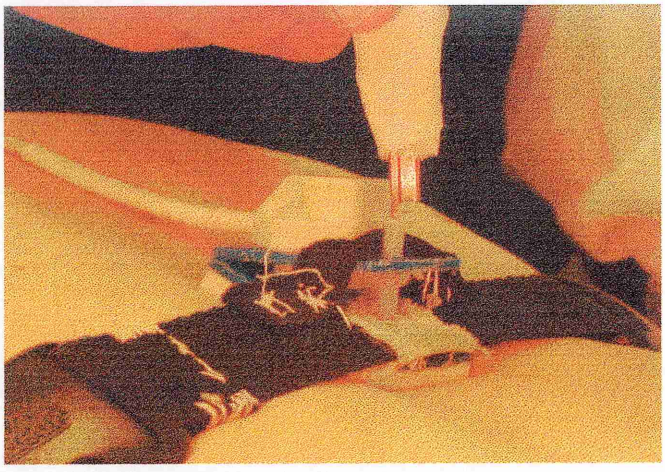


Figure 8.4 Opening the wedge on the sensor module

By using this procedure a zero position for 5 out of 6 recording channels was achieved with the non-zero reading being the displacement between the source and the sensor (Z-translation).

The whole alignment procedure takes, on average, 5 minutes to perform, is very simple and easy to perform and gives meaningful data.

The alignment procedure converts the "unaligned " situation caused by the lumbar lordosis (Figure 8.5) to the aligned situation required (figure 8.6). The prone lying position is therefore used as the zero or reference position.

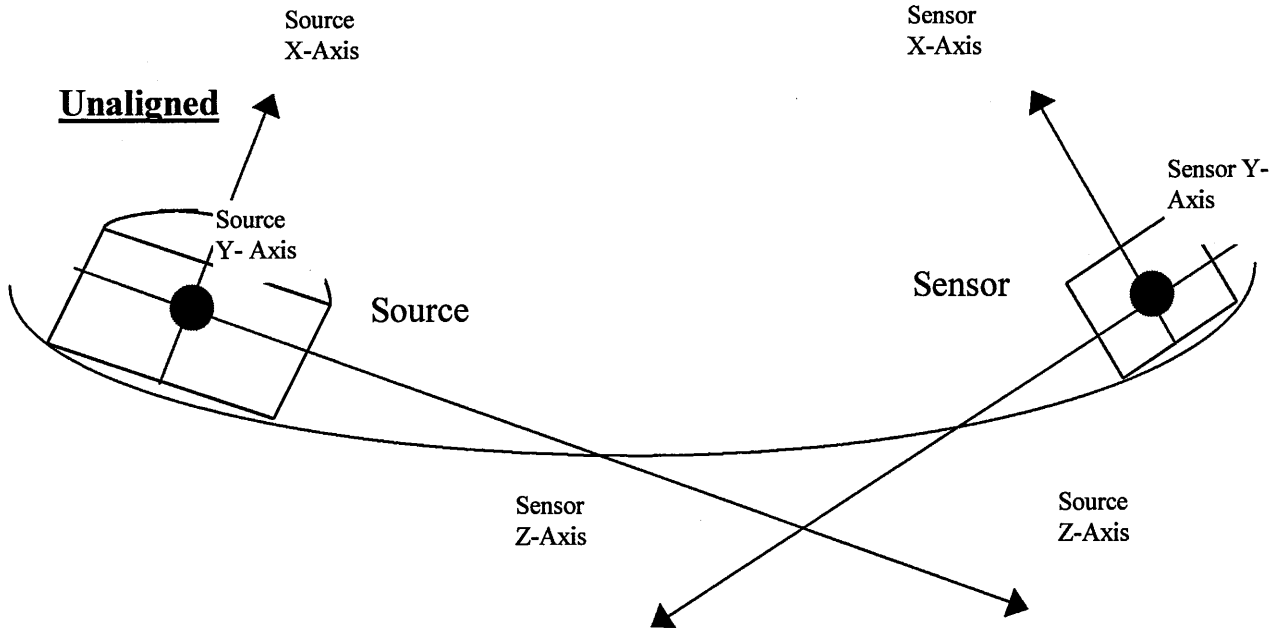


Figure 8.5 Schematic representation of 3Space Isotrak unaligned attachment over the lumbar lordosis in prone lying

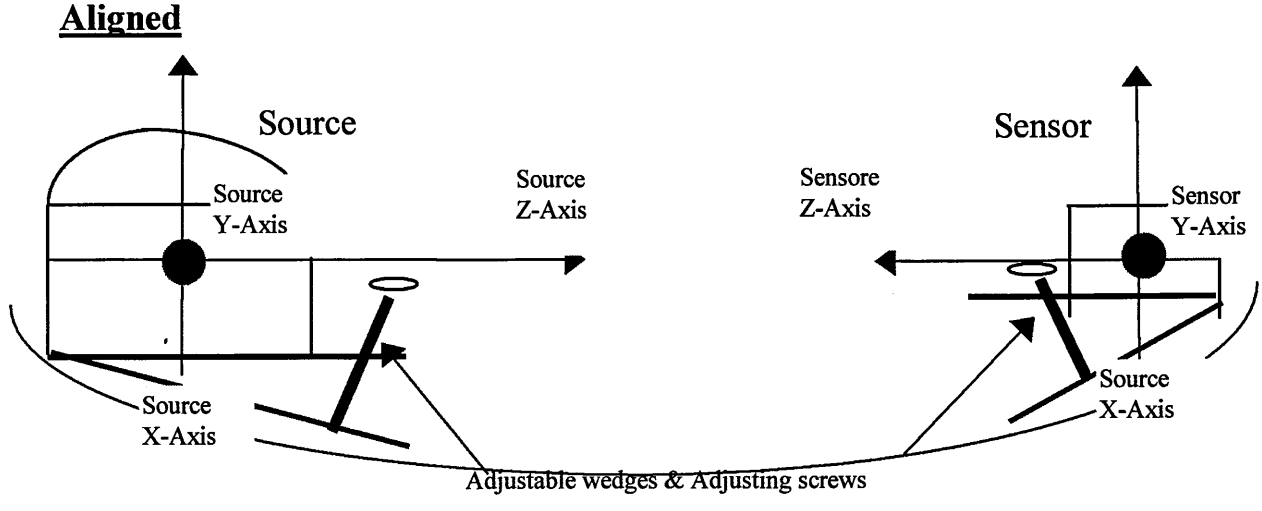


Figure 8.6 Schematic representation of 3Space Isotrak aligned attachment over the lumbar lordosis in prone lying

8.2 Description of the attachment system

The whole measurement system (3 Space Isotrak, Wedges and Trailing cables) was firmly attached to the lumbar spine using 2 nylon belts (figure 8.7). Velcro was sewn onto the outside of the belts so that they easily could be adjusted and adapted to different sizes. In addition, buckles were sewn onto the adjustable plastic wedges and the nylon belts, allowing the source and sensor module to be removed or inserted into the belts (Figure 8.8). The nylon belts were then looped through the buckles and attached to the Velcro

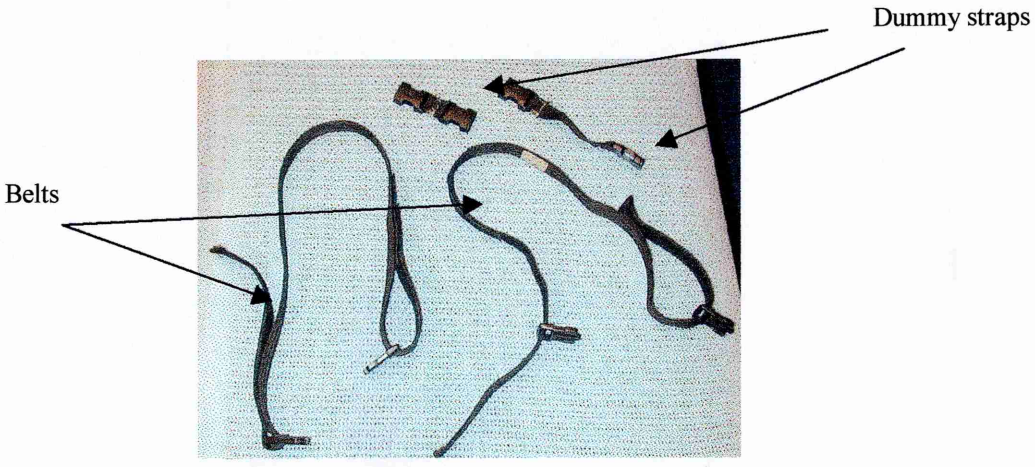


Figure 8.7 Attachment belts and buckles

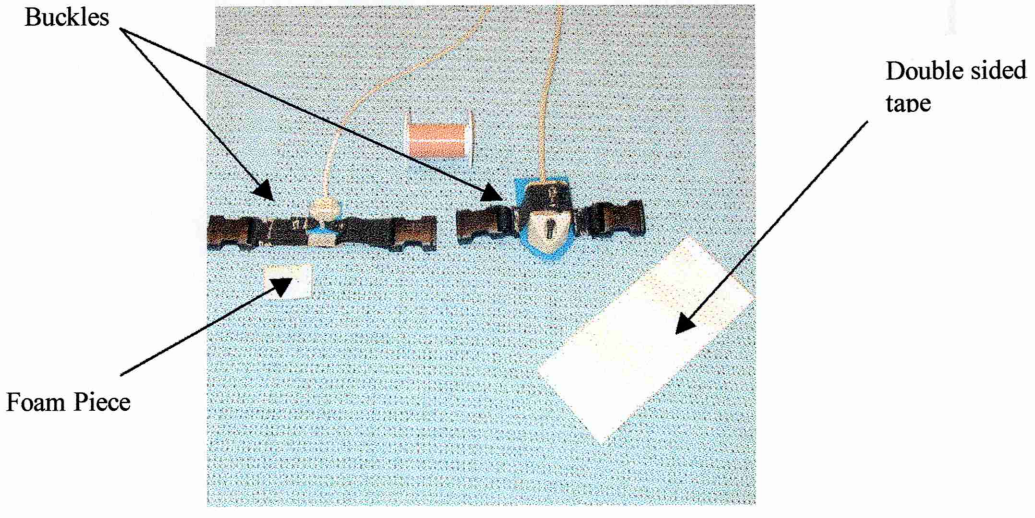


Figure 8. 8 Attachment system

In addition, two small sections of belt with the appropriate buckles were created. These "dummy" straps could be used to replace the source and sensor sections of the belts when attaching the device. This arrangement allowed the belts to be adjusted and provided the possibility to tighten the belt with equal tension on both sides so that no sideways rotation or translation could occur (figure 8.9).

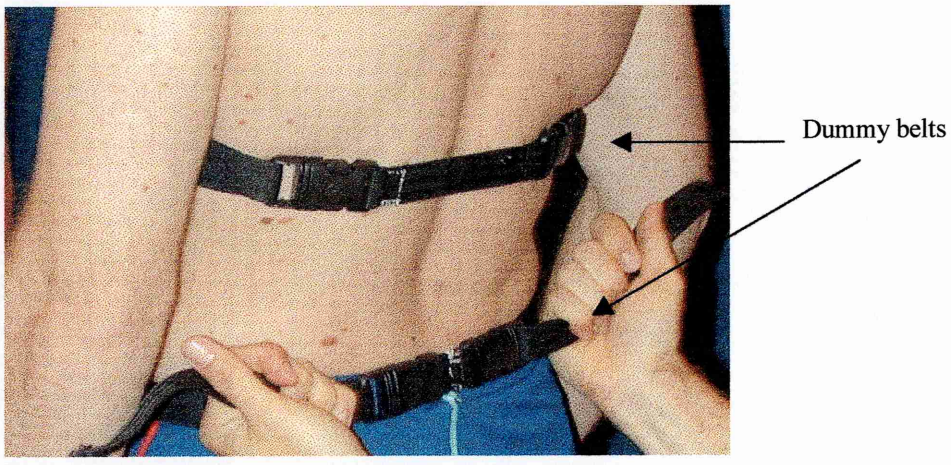


Figure 8.9 Tightening of the attachment belts

The sensor module is relatively light and so it was possible to attach it directly to the skin with the use of double sided tape. However skin movement was reported as a major concern in axial rotation movements by Hindle, (1989) and hence the sensor position may not reflect the actual intervertebral movement that is occurring underneath it.

In order to prevent the sensor from moving on the skin, especially when performing axial rotation, a piece of foam was attached to the baseplate of the adjustable wedge of the sensor using double sided tape (Figure 8.10). The foam was then stuck to the skin using double sided tape. This method kept the sensor firmly in contact with the skin overlying Th12, even in individuals with developed para-spinal musculature, and prevented the sensor from moving on the skin. An elastic strap was used to prevent the wedge from flapping open and the angle of the wedge could be adjusted using the adjusting screw and a plastic screwdriver.

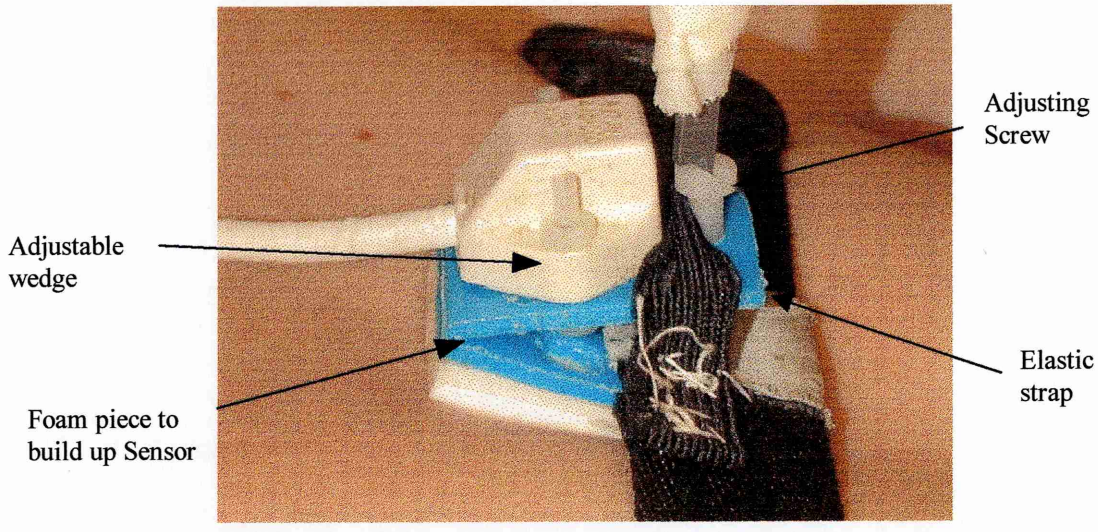


Figure 8.10 Sensor attachment

The source was firmly attached at L5-S1 level using a similar arrangement to that of the sensor but excluding the foam layer

8.3 Procedure for attaching the system

The two nylon attachment belts with the dummy sections in place were strapped around the subject in standing (figure 8.9). The belts were adjusted to approximately the correct locations on the trunk and then tightened. The subject was then asked to lie prone on a treatment table where the belts were opened and the detachable pieces of belt removed (figure 8.11).

Figure 8.11 Subject laying prone attachment belts open

The source and sensor module were subsequently inserted and the belts re-tightened (figure 8.12)

Figure 8 12 Subject laying prone - source and sensor module inserted

The alignment procedure, described previously in section 8.1, was then performed.

8.4 Identification of Anatomical Landmarks

The attachment of any non-invasive measurement system, such as the 3 Space Isotrak poses a major challenge to ensure that once attached, the device gives a fair representation of the actual movement of the spine.

A major problem is the identification, by palpation, of spinal landmarks. McConell (1980) reported low agreement between experienced osteopaths in localising spinal processes. Binkley et al (1995) reported that 95% of the time two different therapists would be within 1.4 spinal levels of each other when making a judgement as to a particular spinal level. Furthermore, McKenzie & Taylor (1997) reported that identification of anatomical landmarks is notoriously unreliable and concluded that further research is required if spinal palpation is to remain a key

component of spinal manipulative therapy. In addition, Burton (1987) questioned the techniques used to identify anatomical landmarks in other non-invasive measurement studies.

Despite this apparent difficulty, most measurement studies using spinous landmark do not mention the identification method used and only indicate, in general terms, that for example L5 was identified by palpation. Therefore it was decided to design an appropriate method which would be reproducible and reliable in identifying the spinous processes of Th12 to L5 in a clinical environment.

The identification procedure designed and used in this study was based on a method used initially by Burton (1987).

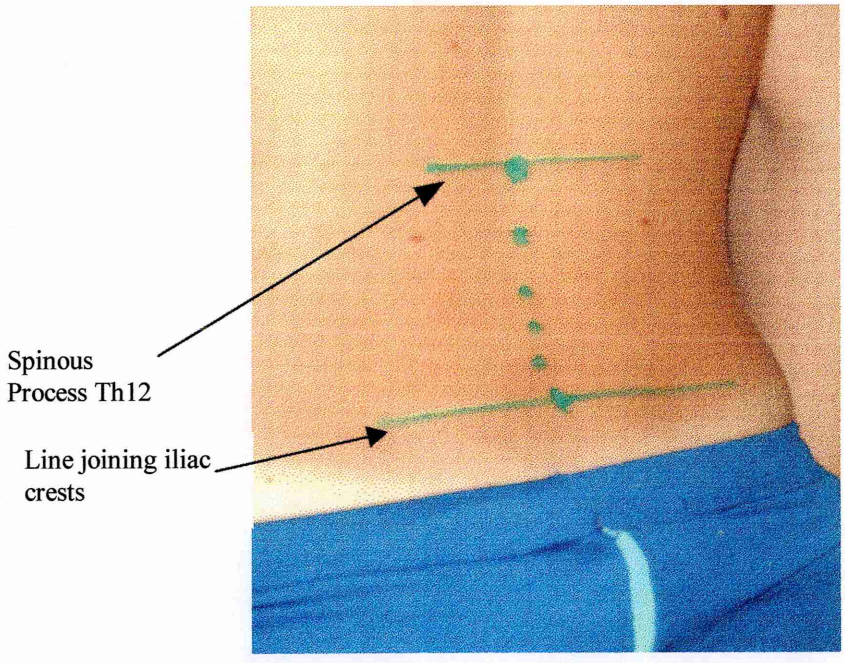


Figure 8.13 location of lumbar spinous processes

This procedure (figure 8.13) was chosen because it uses a point located at the bisection of a line joining the highest points of the iliac crests. Hoppenfeld (1976) and MacGibbon & Farfan (1979) associated this point with the intersegmental space between spinous process of L4 and L5. This point is relatively easy to identify, even in muscular or obese subjects, by putting the lateral

aspect of the index finger of both hands at the highest point of the iliac crest. Using the highest points of the iliac crests represent a major advantage over using the intersection of a line joining the Dimples of Venus (a name give to the two indentations formed by the posterior superior iliac spines) which is often difficult to eyeball or palpate. Moreover, confusion arises as to the anatomical landmarks associated with the Dimples of Venus. Haley et al (1986) associated it with L5 level whereas Hart and Rose (1986) stated that it is the spinous process of S2 that lies at this point.

Having identified the location of the highest points of the iliac crest, an horizontal line was drawn on the skin using a dermatographic pencil. This line joined the highest points of the iliac crests and a vertical mark was on the bisection point indicates the spinous process of L5. Having identified the spinous process of L5 in this manner the spinous process of L4, L3, L2, L1 and Th12 was then found by counting up the spinous processes.

Specially prepared trainer bottoms with a zip at the back allowed for the source to be inserted through the clothes and attached to the skin by double sided tape. The source was placed with the top level with L5. The data were recorded from the middle of the source, which in this configuration lies at approximately the intersegmental level between L5 and S1.

The sensor was attached so that the centre of the sensor coincided with T12.

8.5 Healthy Subjects Testing

After signing the consent form, the height and mass of the subject were recorded.

The sensor and source were then attached to the subject using the method described previously. Subsequently the following 19 tests were recorded.

Test one: Lying prone on the treatment table arms parallel to the body and the body aligned along identifiable markings on the treatment table. A first reading was taken with the unaligned 3 Space Isotrak in place.

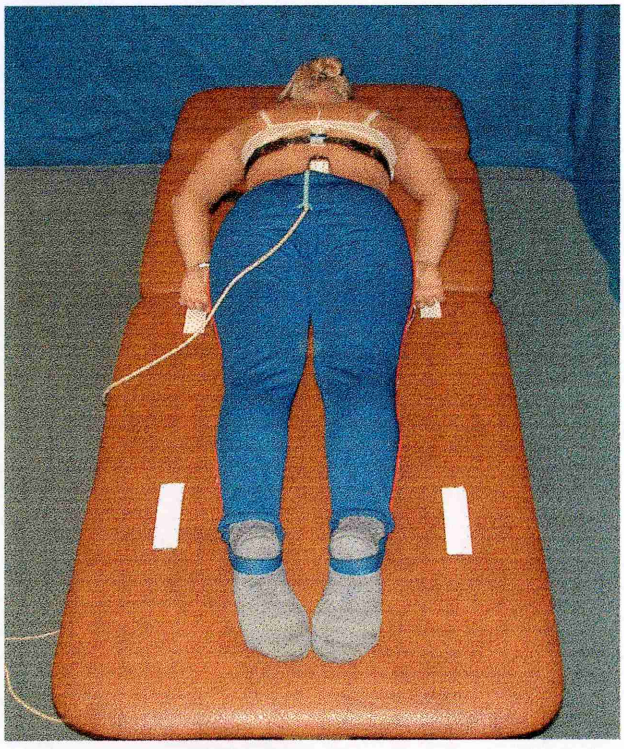


Figure 8.15 lying prone -3 Space Isotrak attached

Test two : In the same position as test one a new reading was taken after the alignment procedure was completed i.e. opening of the adjustable wedges.

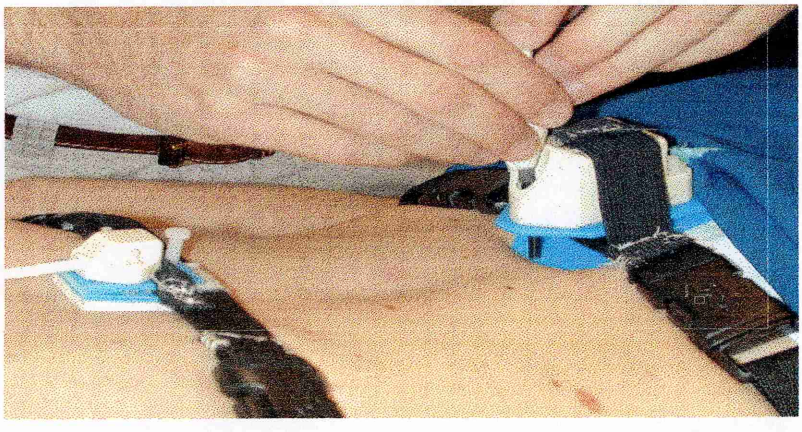


Figure 8.16 Alignment procedure is completed

Test 3: The subject was asked to stand up and position him/herself on a template, feet 20 cm apart, and then to perform the gross movement of forward flexion (figure 8.17). All movements were performed free-paced and the subject was instructed to go as far as possible without bouncing at the end.

The following commands were given :

"Start movement": on which the subjects bent forward to a maximum forward flexion and held this position.

"Return": on which the subjects returned to the upright standing position and held this position

"Relax": on which the test concluded.

The primary investigator pressed time switches in order to mark the different parts of the movement cycle. The following points were associated with a click of the time switch

First click = Recording started

Second click = "Start movement" command given

Third click = End of range achieved

Fourth click = "Return" command given

Fifth click = "Relax" command given

Sixth click = recording ended

This gave data in five sections "Standing", "flexing", "flexed", "returning" and "standing".

The instructions given were "Bend forward at your own pace, keep the knees locked and the feet on the template, let your arms hang freely, stay there and return to starting position"

Figure 8.17 Forward Flexion measurement

Test 4: A similar procedure was used as above except that the subject performed an extension (figure 8.18). The instructions given were: " Look up bend backwards, glide with your hands as far as possible down over your hamstrings, stay there and return to starting position".

Figure 8.18 Extension in standing

Test 5: As above except sidebending to the left (figure 8.19). The instructions given were: "Keeping your knees straight and feet on the template, sidebend to the left by gliding your left hand as far down as possible over your left knee, stay there and return to starting position, keep looking forward and try not to rotate your chest".

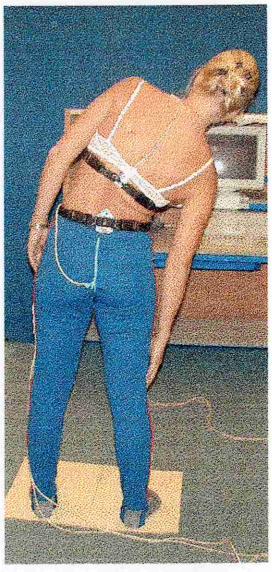


Figure 8.19 Sidebending to the left and right

Test 6: Same test as test 5 but to the right (figure 8.19).

Test 7: Same test but axial rotation to the left (figure 8.20). The instructions given were: "Instructions: Keeping your knees straight and feet on the template, arms crossed in front of your chest, look over your left shoulder, twist your left shoulder as far back as possible, you can twist at the hip but do not lift up your opposite heel from the template, stay there and return to starting position".

Figure 8.20 Axial rotation to the left and right in standing.

Test 8: Same test as test 7 but to the right (figure 8.20)

Test 9: Sitting down & standing up from a 40 cm high stool. The instructions given were:"From standing sit down on the stool behind you, not using your hands in support, stay there and stand up, you can move your feet if you want to".

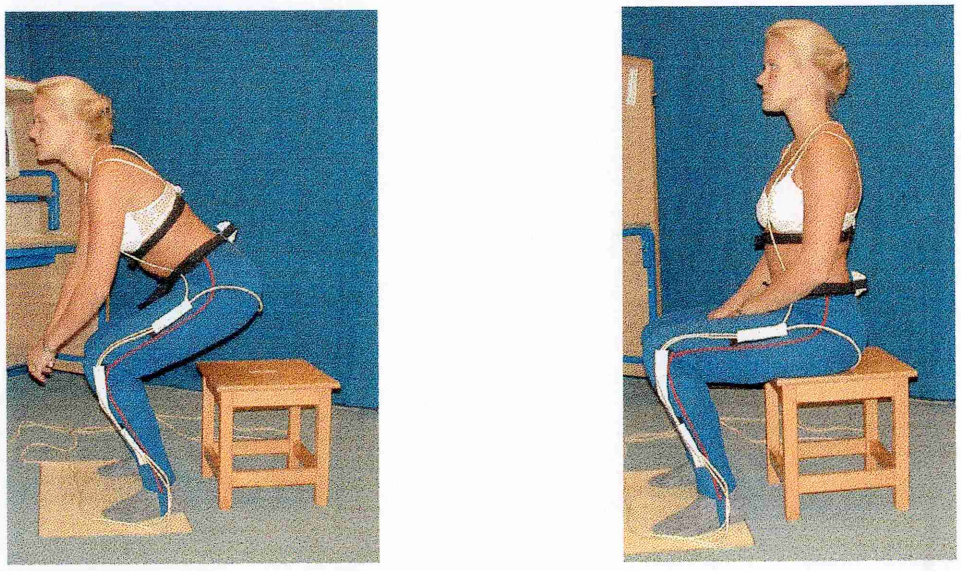


Figure 8.21 Sitting down

Test 10 Going up and down a 20 cm high step (figure 8.24)

Instructions: "go up this step, join your other foot on top of the step, stay there and step down the step at the other side".

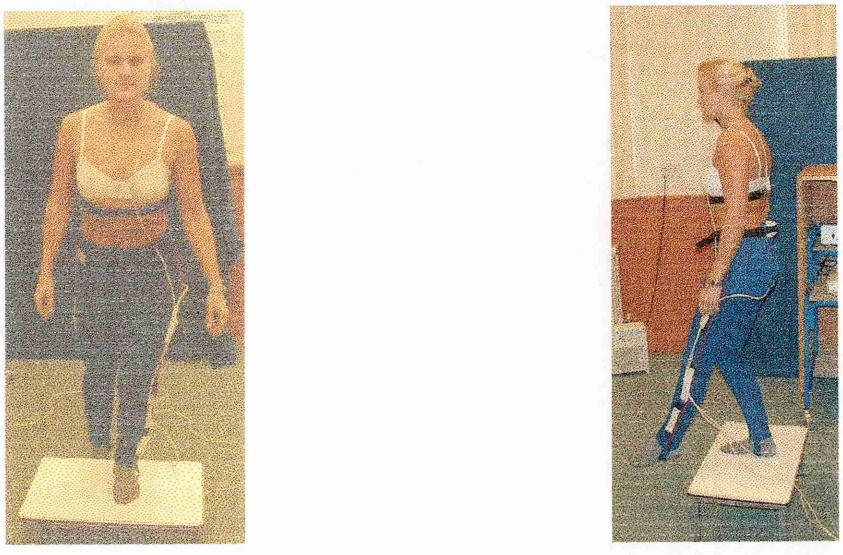


Figure 8. 24 Going up and down a step

Test 11 Picking up a box at the left side and putting it down at the right side (figure 8.25)

Instructions given were: " Keeping your feet on the template, pick up this lightweight box at your left side and bring it in front of you, hold it there for a moment and put it down on your right side parallel with your feet. You can bend your knees if you want to".

Figure 8.25 Picking up a box on the left side and putting it down on the right side

Test 12 Picking up a box at the right and putting it down at the left side

Same test as test 11 but now from the right to the left.

Test 13, 14, 15, 16, 17, 18 were similar to tests 3-8 i.e. flexion, extension, sidebending to the left & right and axial rotation to the left & right, but were performed in a sitting position. The tests in sitting position were carried out because there is controversy in the literature about the protocols for testing of lumbar mobility. Most textbooks recommend testing of lumbar spinal motion in standing position (Maitland, 1986; Cyriax, 1982). However several authors measure axial rotation from a sitting position in order to stabilise the pelvis (Magee, 1987; Kaltenborn, 1989; Stoddard, 1978). Therefore and in order to investigate the effect of hip flexion (i.e. sitting position) on lumbar mobility the measurements of the gross movements were repeated but from a sitting position.

Subjects were seated on a stool 40 cm high, arms hanging freely to the side (figures 8.26).

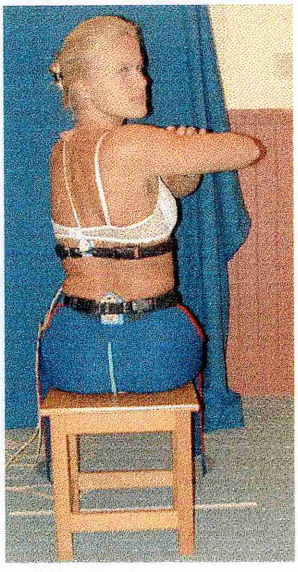


Figure 8 26 Seated gross movements tests e.g. Axial Rotation

Test 19: This test was a repeat of the first test i.e. lying down on the table in prone lying position. This test was performed in order to record any changes in the positioning of the device.

8.6 Low back Patients Testing

The patients were met in the waiting area of the physiotherapy department of the Western General Hospital, Edinburgh by the principal investigator. In the testing cubicle the patients were asked if they had any queries about the testing procedure or the project and were asked to read and sign the consent form.

In order to have a representative picture of how the patients group was affected by low back pain in their daily activities (disability) a Roland and Morris Disability Questionnaire (Appendix 8.3) was used.

Disability is defined as the diminished capacity for everyday activities and gainful employment (Allan & Waddell, 1989). Although disability is predicated on objective determination of what patients can or cannot do, this usually depends on what patients report, and their reports are determined as much by patients' attitudes, beliefs and motivations as by objectively determined physical pathology. Consequently, disability determination will always be highly subjective, based on the clinicians attitude and beliefs and the credibility they give to patient's subjective report (Turk, 1991). However, clinicians use this information to form an impression about a patient's functional status at a certain time and to determine whether the functional status has changed over the course of a treatment period (Stratford & Binkley, 1999).

Waddell & Main (1984) have shown that disability in activities of daily living can be assessed reliably during clinical interview or can alternatively be assessed by self-report questionnaires.

A number of self-report measures of functional capacity are available. Waddell & Turck (1992) found the Roland and Morris Disability Questionnaire (RMQ) (Appendix 8.3) to be one of the best developed and established disability questionnaires available. Their assessment was based

on a better factor structure, score distribution, and clinical utility than other competing functional status measures applied to patients with low back pain. Jensen et al (1992) examined the reliability and validity of the RMQ as a measure of dysfunction among low back patients. Test-retest stability coefficients indicated that the RMQ was generally as reliable as the Sickness Impact Profile (Berger et al, 1981) from which the RMQ is derived. The pattern of relationship between RMQ and several other pain-related measures supported the conncurrent validity of the RMQ. Furthermore, a recent study by Stratford and Binkley (1999) have illustrated how this questionnaire could be efficiently incorporated into clinical practice to aid decision making concerning individual low back pain patients.

The RMQ (appendix 8.3) is a self-administered 24-items questionnaire that assesses pain-related disability (Roland & Morris, 1983a &b). Each of the 24 items is scored as 1 if endorsed. Thus, scores can vary from 0 (no disability) to 24 (severe disability). Stratford and Binkley (1999) reported the average initial scores of 7 clinical trials on low back pain (Roland and Morris, 1983b; Hadler et al, 1987; Jensen et al, 1992; Beurskens et al, 1996, Leclaire et al, 1997; Riddle et al, 1998 and Stratford et al, 1998). The mean score of these 7 trials was 11.1. The trial by Leclaire et al (1997) made a distinction between lumbar pain (10.9) and radiculopathy (14.1). Stratford and Binkley (1999) recognises that information concerning customary RMQ discharge scores is sparse but believed that patients viewed as being successes (e.g. those meeting their treatment goals, undergoing an important change, or allowed to undergo the natural history of low back pain over 12 weeks) typically have RMQ scores less than or equal to 4 RMQ points

The present pain level of the patients was recorded on a Visual Analogue Scale before (appendix 8.1) and after (appendix 8.2) the intervention.
Gramlings and Elliot (1992) evaluated and confirmed the reliability and validity of this pain scale in a clinical setting.

Patients, included in the trial after assessment, were asked to rate their pain level on 2 occasions by putting a mark along a 100 mm line. The end of the line (sometimes called the anchors) are labelled "No pain" on the left and "Worse pain imaginable " at the other. The patient simply placed a mark on this continuum. The distance from the left-hand anchor is their rating of how severe their pain was at that time. It was emphasised for the patients that it was the pain level at that moment which was important i.e. how painful or discomfortable their low back pain was at that particular moment in time. The level of analgesic intake was also recorded, but none of the assessed patients had taken any analgetics within 3 hours of the measurement. The pain measurement procedure was repeated after the mobilisation treatment was finished.

In order to avoid bias, a fresh 100 mm line with no marks on it was presented to the patient on each occasion

Height and mass were then recorded and the same testing sequence as for the healthy subjects was followed. However, the patients were instructed not to go over the pain barrier and to stop the movement if any discomfort or pain should arise. It was stressed that this testing was not a performance test but an attempt to record how low back patients move in comparison with healthy subjects.

8.7 Repeatability of the measurement procedures

In a clinical setting it is obviously desirable to be able to conduct as few repeats of a movement as possible, ideally to measure it only once. Further it is necessary to show the results of the new attachment and alignment procedure were repeatable in order to use the system.

A repeatability study of both the attachment and measurement procedure was therefore undertaken with the measurements of the gross movements being repeated with the subject in both standing and sitting.

Twenty healthy subjects (10m, 10f) in the 20-29 age group were tested twice on the same day with 3 hours between the 2 tests. The measurement system was completely removed in between the two tests and both tests were performed in the afternoon to avoid diurnal variation. The spinous process of Th12 and L5 were identified at the start of the first session and were marked with indelible ink, as this would enhance the reliability of the attachment procedure as well as representing the clinical testing procedure to be used later in this study.

The gross movements of flexion, extension, sidebending to the left and right and axial rotation to the left and right, taken in 2 test sessions 3 hours apart, were analysed.

The test procedure described under section 8.5 (healthy subjects) was followed.

The data from the 3 Space Isotrak were analysed using a purpose written analysis program and group averages as well as individual plots were performed (in excel 5.0). Statistical analysis was carried out using the SPSS software package.

Table 8.1 gives the mean angle (in degrees) recorded for the group for each function in each test along with the percentage change the absolute difference in the means and Cronbach's α test for internal consistency.

Standing

Movement	Test one	Test two	% Difference	Absolute Difference	Cronbach 's α
Flexion	57.7	57	-1.2	0.7	0.927
Extension	29.8	28.6	-4.0	1.2	0.921
SBL	25.4	25.6	+3.9	0.2	0.919
SBR	26.2	24.4	-6.8	1.8	0.879
ARL	16.5	14.7	-10.9	1.8	0.688
ARR	15.7	14.1	-10.1	1.6	0.894

Sitting

Movement	Test one	Test two	% Difference	Absolute Difference	Cronbach 's α
Flexion	40.2	42.1	+4.5	1.9	0.845
Extension	31.3	30.8	-3.1	0.5	0.702
SBL	27.2	26.9	-1.1	0.3	0.889
SBR	28.6	26.7	-3.1	1.9	0.851
ARL	21	19.1	-9.0	1.9	0.852
ARR	19.6	18.4	-6.1	1.2	0.927

Table 8.1 Repeatability of movement testing in standing and in sitting (test-retest of 20 healthy subjects 10M +10 F in the 20-30 age category)

Table 8.1 demonstrate how consistently a group of subject was able to perform each movement and how repeatable the 3 Space Isotrak and measurement protocol were in recording their performance. Nearly identical values were recorded during the two tests with Cronbach's alpha values indicating good to excellent repeatability.

In addition there are clear differences in axial rotation values obtained in standing and in sitting. Axial mobility values in sitting were markedly higher than in standing as shown (Table 8.1.) These results are consistent with the findings of Pearcy (1993) and indicate both that differences are present in the ranges of motion of the lumbar spine in sitting and standing and that the 3 Space Isotrak system and measurement protocol used was able to record these changes.

Having established the measures to be repeatable the system was used to create a normal database and to carry out a randomised controlled trial to investigate the effects of spinal mobilisation techniques on lumbar flexibility.

9. Results: Subject Characteristics

9.1 Healthy Subjects Characteristics

One hundred healthy subjects, divided in 5 age cohorts (20-29 years; 30-39 years; 40-49 years; 50-59 years and 60+ years) were tested. Each age cohort included 20 subjects, 10 males and 10 females.

Table 9.1 provides the age, height and mass profiles of the healthy subjects. The individual characteristics for each subject are included in appendix F (9.1).

	Females (n=50)					Males (n=50)				
Age Cohort	**20-29**	**30-39**	**40-49**	**50-59**	**60+**	**20-29**	**30-39**	**40-49**	**50-59**	**60+**
Mean Age (y.)	24.5 (2.2)	35.8 (2.5)	44.9 (2.7)	54.6 (2.5)	71.4 (3.7)	24.5 (2.5)	35.6 (2.1)	46 (2.3)	54.9 (2.2)	65.9 (4.8)
Mean Height(m)	1.67 (2.6)	1.66 (6.5)	1.64 (6.1)	1.63 (4.4)	1.60 (5.4)	1.78 (5.4)	1.78 (5.2)	1.74 (8.5)	1.76 (7.6)	1.73 (6.3)
Mean Mass(kg)	64.2 (8.8)	65.5 (12.3)	65.7 (9.6)	65.9 (6.0)	66.6 (6.9)	77.5 (8.6)	80.2 (9.0)	82.1 (8.4)	82.1 (12.3)	80.7 (11.1)

Table 9.1 Characteristics of healthy subjects: mean (SD)

The mean age of each age cohort was situated near the middle of the age range except for the females 60+ group where the mean age was 71.4 (3.7).

The mean height of the subjects decreased gradually with increasing age in both males and females groups with males on average 0.10 m. taller than females.

The mass of the subjects increased slightly (3 kg) with increasing age in both males and females with males on average 15 kg heavier than females.

9.2 Patient Group Characteristics

A total of 180 low back patients were considered for inclusion in the trial by 6 participating physiotherapists over a period from 10th of September 1998 until the 28th of April 1999.

Forty-one patients of the 180 assessed (22.7%) were deemed suitable for treatment by mobilisation and consequently included in the clinical trial.

Figure 9.1 shows the inclusion rate for the 6 physiotherapists included in the trial.

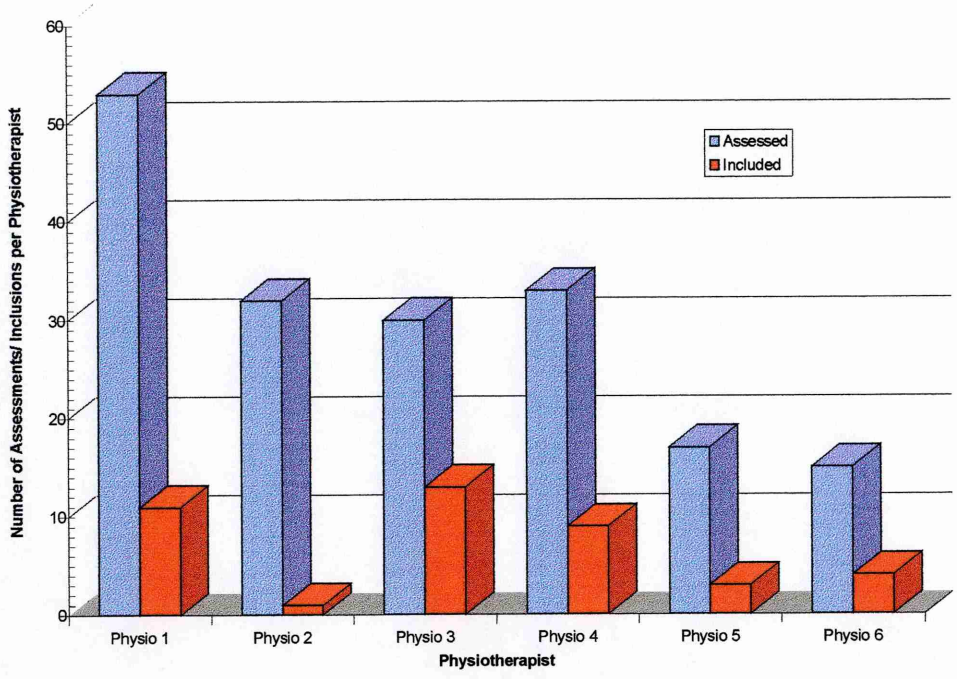


Figure 9.1 Number of patients assessed and included in clinical trial.

There was a large variation between physiotherapists in the number of patients included in the trial (3% to 43%) after initial assessment. The average inclusion rate for the six participating physiotherapists was 1 out of every 4 patients assessed (22.7%).

Physiotherapist number 2 only included 3% of subjects assessed and hence was withdrawn from the trial in December 1998.

Different reasons for non-inclusion in the trial were given. Table 9.2 provides an overview of the main reasons, given by the participating physiotherapists, for non-inclusion in the clinical trial.

The main reason given for non-inclusion in the trial was "not a LBP problem"(27.3%), which was a conglomerate of different reasons i.e. a psychiatric component, general pain syndrome, postural problems or an inflammatory process.

"Hypermobility or normal mobility", in which case mobilisation treatment is contra-indicated, was also a common reason for non-inclusion (20.1%).

All 41 patients included in the trial were considered suitable candidates for mobilisation by the assessing physiotherapists.

Reason for non-inclusion in clinical trial after initial assessment	Percentage responses (n=139)
Not a low back problem/ Psychiatric component/ General pain syndrome/Postural problem/ Inflammatory process	27.3 %
Good mobility or hypermobility	20.1 %
Patients did not attend assessment session	12.2 %
Too chronic	11.5%
Patient recovered/ no further treatment required	10.7 %
Patient suitable for mobilisation treatment but unable to participate	4.3 %
Mobilising Exercises more indicated than mobilisation	3.5 %
Obesity	2.8 %
Previous surgery/ considered for surgery	2.8 %
Osteoporosis	1.4 %
Too acute	1.4 %
Unable to attend further treatment sessions	0.7 %
Aggravated since initial GP referral/ Specialist referral	0.7 %

Table 9.2 Reasons for non-inclusion of LBP-patients in clinical trial

9.2.1 Delayed Intervention & Intervention group characteristics

The block-randomisation allocated 21 patients (10 male, 11 female) to the "delayed intervention" group and 20 patients (7 male, 13 female) to the "intervention" group.

The delayed intervention & intervention group characteristics are presented in table 9.3. The characteristics of the individual patients included in the delayed intervention & intervention groups are given in appendix G (9.2). No significant differences in age ($p=0.824$), height ($p=0.459$) or mass ($p=0.945$) were found between two groups

(Independent t-test, two-tailed, equal variances). However, it should be noted that the gender balance of the delayed intervention and intervention groups was different with a higher proportion of females in the intervention group.

	Delayed Intervention Group n=21 (10m/11f)	Intervention Group n=20 (7m/13f)
Mean Age (y) (s.d.)	46.0 (12.8)	45.1 (13.1)
Mean Height(m) (s.d.)	1.68 (0.07)	1.70 (0.11)
Mean Mass (kg) (s.d.)	71.9 (14.1)	72.2 (12.9)

Table 9.3 Characteristics of the delayed intervention & intervention groups

9.2.2 Disability profile of the patient group

All patients, included in the clinical trial, filled out a Roland and Morris Disability questionnaire before the first measurement series was taken.

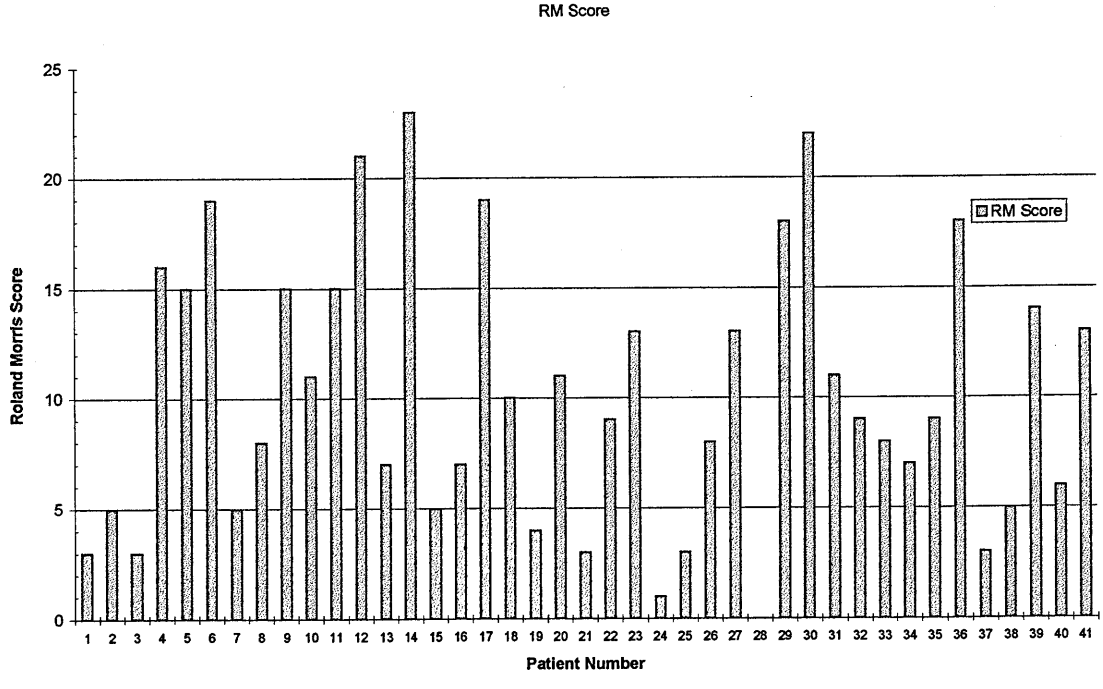


Figure 9.2 Roland Morris Disability Questionnaire Score for 41 Patients included in the RCT.

The mean Roland & Morris Questionnaire score for all 41 patients was 10.1 (5.1). These scores are in close agreement with the mean values 11.3 (5.5) of 7 clinical trials (Roland and Morris, 1983b; Hadler et al, 1987; Jensen et al, 1992 .Beurskens et al, 1996, Leclaire et al, 1997, Riddle et al, 1998 and Stratford et al, 1998 mentioned in a study by Stratford & Binkley (1999).

The delayed intervention and intervention groups were not significantly different in mean disability score ($p = 0.468$, 95% Confidence Interval for the difference between population means was -2.48, 5.30) (Independent samples t-test, assuming equal variances, two-tailed).

The difference in disability level between acute (pain < 6 weeks) and chronic (pain > 6 weeks) pain patients were analysed (Independent Samples t-test, assuming equal variances, two-tailed). No significant difference in disability level was found ($p=0.809$, 95% Confidence Interval for the difference between population means was: -4.42, 3.46).

A frequency analysis and rank order of the separate questions is provided in Table 9.4.

Roland Morris Questionnaire- Results

Question Number	Description	% response of 41 patients	Rank
1	I stay at home most of the time because of my back	2	22
2	I change position frequently to try and get my back comfortable	78	1
3	I walk more slowly than usual because of my back	58	4
4	Because of my back, I am not doing any of the jobs that I usually do around the house	46	11
5	Because of my back, I use a handrail to get upstairs	24	19
6	Because of my back, I lie down to rest more often	39	15
7	Because of my back, I have to hold on to something to get out of an easy chair	36	16
8	Because of my back, I try to get other people to do things for me	32	17
9	I get dressed more slowly than usual because of my back	54	7
10	I only stand up for short periods of time because of my back	46	11
11	Because of my back I try not to bend or kneel down	54	7
12	I find it difficult to get out of a chair because of my back	56	6
13	My back is painful almost all the time	44	13
14	I find it difficult to turn over in bed because of my back	51	9
15	My appetite is not very good because of my back pain	2	22
16	I have trouble getting on my socks (or stockings) because of the pain in my back	63	2
17	I only walk short distances because of my back pain	44	13
18	I sleep less well because of my back	58	4
19	Because of my back, I get dressed with help from someone else	7	20
20	I sit down for most of the day because of my back	3	21
21	I avoid heavy jobs around the house because of my back	63	2
22	Because of my back, I am more irritable and bad tempered with people than usual	32	17
23	Because of my back, I go upstairs more slowly than usual	51	9
24	I stay in bed most of the time because of my back	0	24

Table 9.4 Analysis of Roland-Morris Disability Questionnaire

9.3 Physiotherapists Characteristics

A total of 6 physiotherapist took part in the clinical trial. All physiotherapists were registered by the Council of Professions Supplementary to Medicine (CPSM) and members of the Chartered Society of Physiotherapy (CSP).

The characteristics of the participating physiotherapists are represented in Table 9.5

Physio-therapist	Gender	Age	Position	Qualifi-cation	Years Qualified	Years experience with LBP treatment	MACP*-status
1	Female	34	Senior I	BSc	12	7	Yes
2	Female	32	Senior I	BSc	10	10	Yes
3	Male	40	Senior I	Diploma	14	10	No
4	Female	27	Senior II	BSc	7	4	No
5	Female	28	Senior II	BSc(Hon)	5	3	No
6	Female	28	Senior I	Diploma	8	5	No
Mean (s.d.)		31.5 (5.0)			9.5 (3.5)	6.3 (3.2)	

*MACP= Manipulative Association of Chartered Physiotherapists

Table 9. 5 Characteristics of the six participating physiotherapist

All participating physiotherapists had extensive experience in outpatient treatment. Most of the physiotherapists qualified with a degree. Although only 2 out of 6 participating physiotherapists were registered with the Manipulative Association of Chartered Physiotherapists (MACP) all of them had at least 3 years experience with low back pain treatment. In addition all of the physiotherapists had attended a number of specialised post-graduate courses in the treatment of low back problems (table 9.6). Moreover all of the participating physiotherapists indicated that they used mobilisation techniques for low back pain treatment on a daily basis in their clinical practice

.

Physiotherapist	Number of relevant courses taken	LBP related Courses taken
1	5	MACP-Courses Maitland Techniques Course Muscle Imbalance Neurodynamics Myofascial Release
2.	3	McKenzie Techniques Course Maitland techniques Courses Muscle Imbalance
3	6	Cyriax, Orthopaedic Medicine MACP-Courses Maitland Techniques Courses Scandinavian System Courses Muscle Imbalance Courses Neurodynamics
4	3	McKenzie Courses NAGS+SNAGS Muscle Imbalance
5	3	McKenzie Courses MACP-Courses Maitland techniques Courses
6	4	McKenzie Courses Maitland techniques Courses Muscle Imbalance Chronic Pain Management

Table 9. 6 LBP-related postgraduate courses taken by the participating physiotherapists

9.4 Profile of Mobilisation techniques and different mobilisation grades used by 6 participating physiotherapists during the clinical trial.

All of the participating physiotherapists received training in the "Maitland "system during their pre-registration training and the mobilisation techniques advocated by this system were mainly applied by the physiotherapists during the clinical trial. However, some physiotherapists indicated that they used diagnostic techniques from other Orthopaedic Manipulative Therapy systems i.e. Cyriax (Cyriax, 1986) or McKenzie (McKenzie, 1981) systems.

The Maitland treatment techniques (Maitland, 1986) used by the six physiotherapists are grouped in:

1. Posterio-Anterior Central Vertebral Pressure
2. Postero-Anterior Unilateral vertebral pressure
3. Transverse Vertebral pressure
4. Rotation

Table 9.7 provides a summary of the relative use of the different techniques by the individual physiotherapist. The full results are displayed in appendix 9.3.

Technique Used	Frequency of use	Lumbar Level most frequently mobilised
Posterior Anterior vertebral pressure	54 times	L4
Posterior Anterior Unilateral	13 times	L4
Transverse pressure	12 times	L4 & L3
Rotation	20 times	NA
Total	99	L4

Table 9.7 Relative frequency of different mobilisation techniques and the level of application

Overall, posterior-anterior lumbar central pressure was the dominant technique (54%) used. This technique was used more than twice as often as the rotatory technique (20%), with transverse vertebral pressure (12%) and posterior-anterior unilateral vertebral pressure (13%) only sporadically used.

The spinous processes of L4 was the level which was mobilised most often, regardless of the technique used.

The forces exerted by the physiotherapist during the application of the techniques are divided by Maitland into 5 different grades (Maitland, 1986). Table 9.8 provides a

summary of the frequency with which the intended grades were used and on which lumbar level the forces were applied. The results are comparable to an unpublished study by McCrea (2000). They indicate that the mobilisations delivered in this study where typical of the mobilisation therapy in general. The full results are included in appendix 9.4.

Grade Used	Number and Percentage	Lumbar level most frequently used
I	8 (4.6)	L4
II	48 (28.9)	L4
III	81 (47)	L3
IV	27(15.6)	L4
V	8 (4.6)	L5
Total	172(100%)	L4

Table 9.8 Relative use of mobilisation forces (in grades) stated to be used and the stated level it was most frequently applied to.

Grade III showed to be the predominantly used mobilisation grade (47%), followed by grade II (27.9%) and Grade IV (15.6%). Grade I (4.6) and grade V (4.6%) were only sporadically used.

10. Results: Healthy Subjects

10.1 Introduction and Data Analysis

When measurements are required to be made outside of the laboratory, the 3 Space Isotrak can be transported in a specially constructed carrying case and can, if necessary, be connected to a small "laptop" personal computer which makes the whole system compact and easy to accommodate in confined spaces e.g. physiotherapy treatment rooms.

Once the three angles of flexion-extension, lateral bend and axial rotation are obtained from the 3 Space Isotrak for each movement, various analyses of the data can take place.

A novel computer program was written to control the device and to collect and process the data. This computer program called GuyCy amalgamated the 2400 data-text files (120 subjects x 20 tests) into 240 summary files (12 groups of 20 tests) i.e. the 2400 individual files summarised per age cohort. In addition, this program processed the data so that the 2400 individual files and the 240 summary data files were normalised for time i.e. interpolated. This normalisation procedure was necessary because all measurements were executed at free pace which meant that every individual performed a particular movement at a different speed and so the movement of interest occurred at different points in time (Figure 10.1). This makes comparison by simple overlay of the individual and group plots difficult.

However, comparison of the pattern in the traces was made possible by using interpolation techniques. The computer program divided each time segment (the time between two activations of the time switches) into 100 equal pieces (100%) regardless of the time taken between them. For example if it took 10 s to perform a particular segment of the movement then 400 data samples were produced (40 Hz x 10).

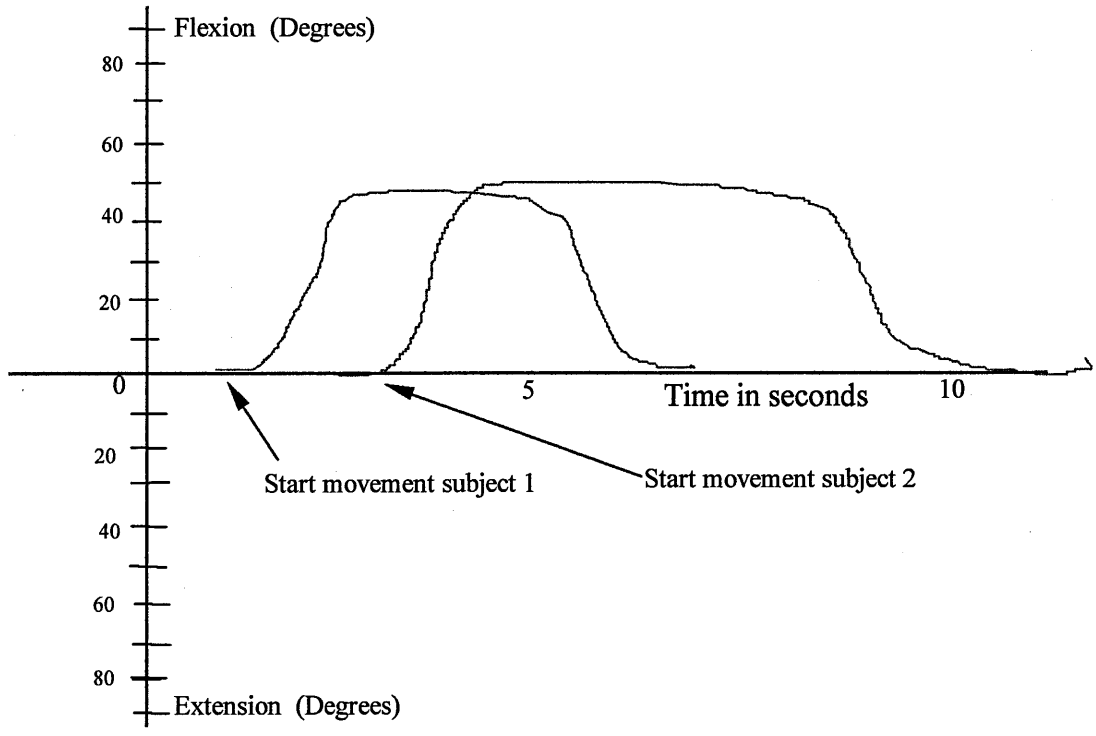


Figure 10.1 Plot of 2 subjects performing forward flexion free-paced

These 400 points were then interpolated into 100 percentage points to produce a normalised plot. These percentage points could then be compared between subjects and used to produce interpolated group files (e.g. figure 10.2). Five segments were marked in the data-file during the measurement by pressing the time-switches when the subject started or ended predetermined points in the movement (see chap. 8: protocol). Hence this interpolation process was repeated five times, once for each segment of the curve (figure 10.2).

This normalisation procedure did not alter the general shape of the curve but allowed for comparison of the pattern and range of the movement between subjects and subject groups.

Finally a macro was written in a spreadsheet (Excel 5.1) which allowed the three angles to be plotted against time in order to give a three dimensional representation of the movement (figure 10.3). Two separate standard plots were produced, one representing the individual

traces for each subject in the age group (e.g. figure 10.3) and another one displaying the mean values for that age group (e.g. figure 10.2).

The results pertaining to the healthy subjects will be presented in the following order:

1. Analysis of the 6 gross movements including:

- a presentation of the main and individual excursion plots for 100 healthy subjects
- a presentation of the excursion values of the main and coupled movements recorded in a standing position.
- the influences of age, gender, height and mass on excursion values
- a normative database for the 6 gross movements

2. Analysis of the 4 functional movements with a presentation of the excursion plots and values.

10.2 Analysis of the 6 gross movements in 100 healthy subjects

10.2.1 Lumbar mobility excursion plots in 100 healthy subjects measured from a standing position

The interpolated plots of 100 healthy subjects performing the gross movements of forward flexion, extension, lateral bending and axial rotation in standing are displayed in figures 10.2 to 10.13.

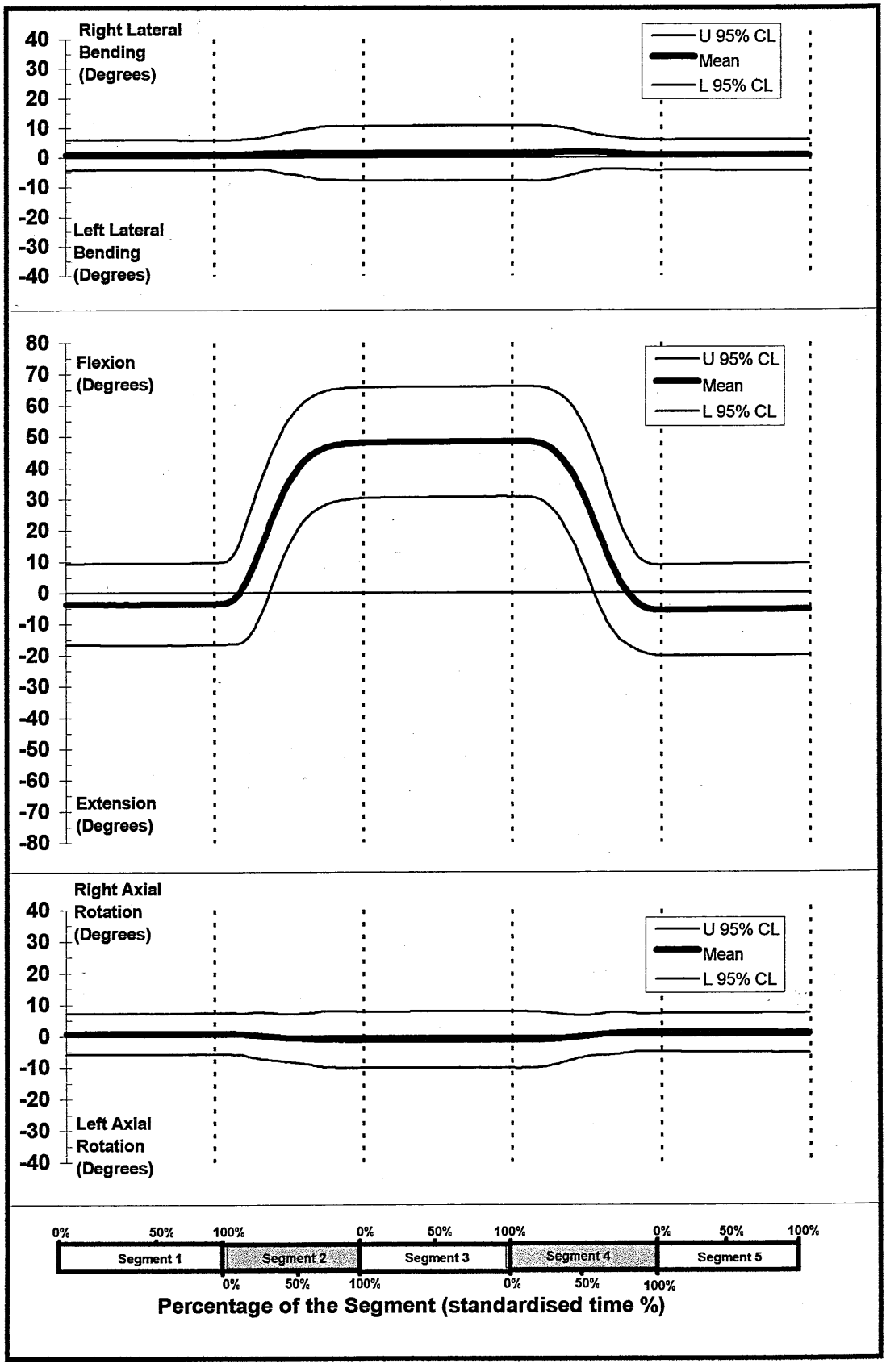


Figure 10.2 Interpolated mean plot of 100 healthy subjects performing forward flexion in standing

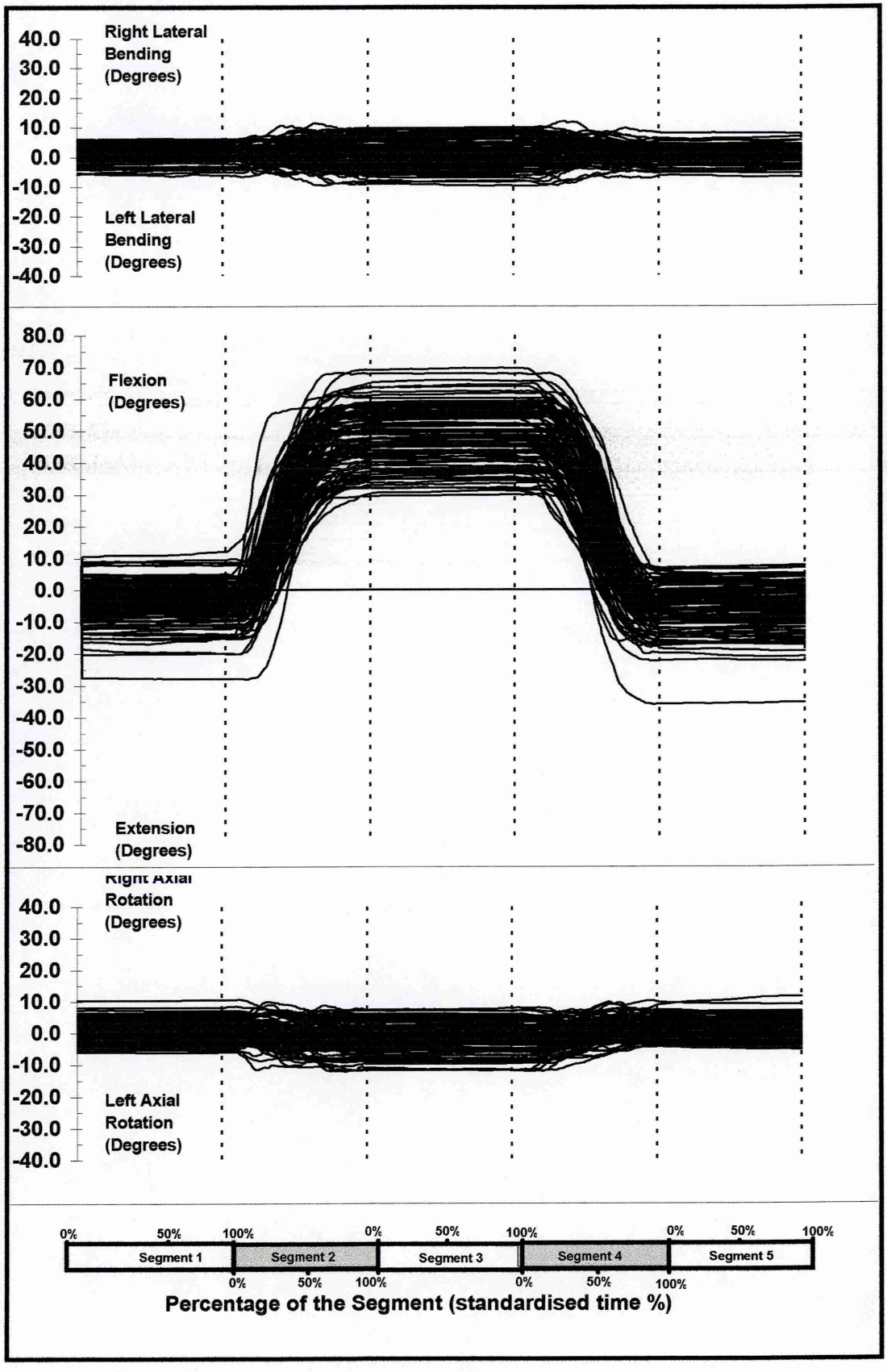


Figure 10.3 Interpolated Individual plots of 100 healthy subjects performing forward flexion in standing

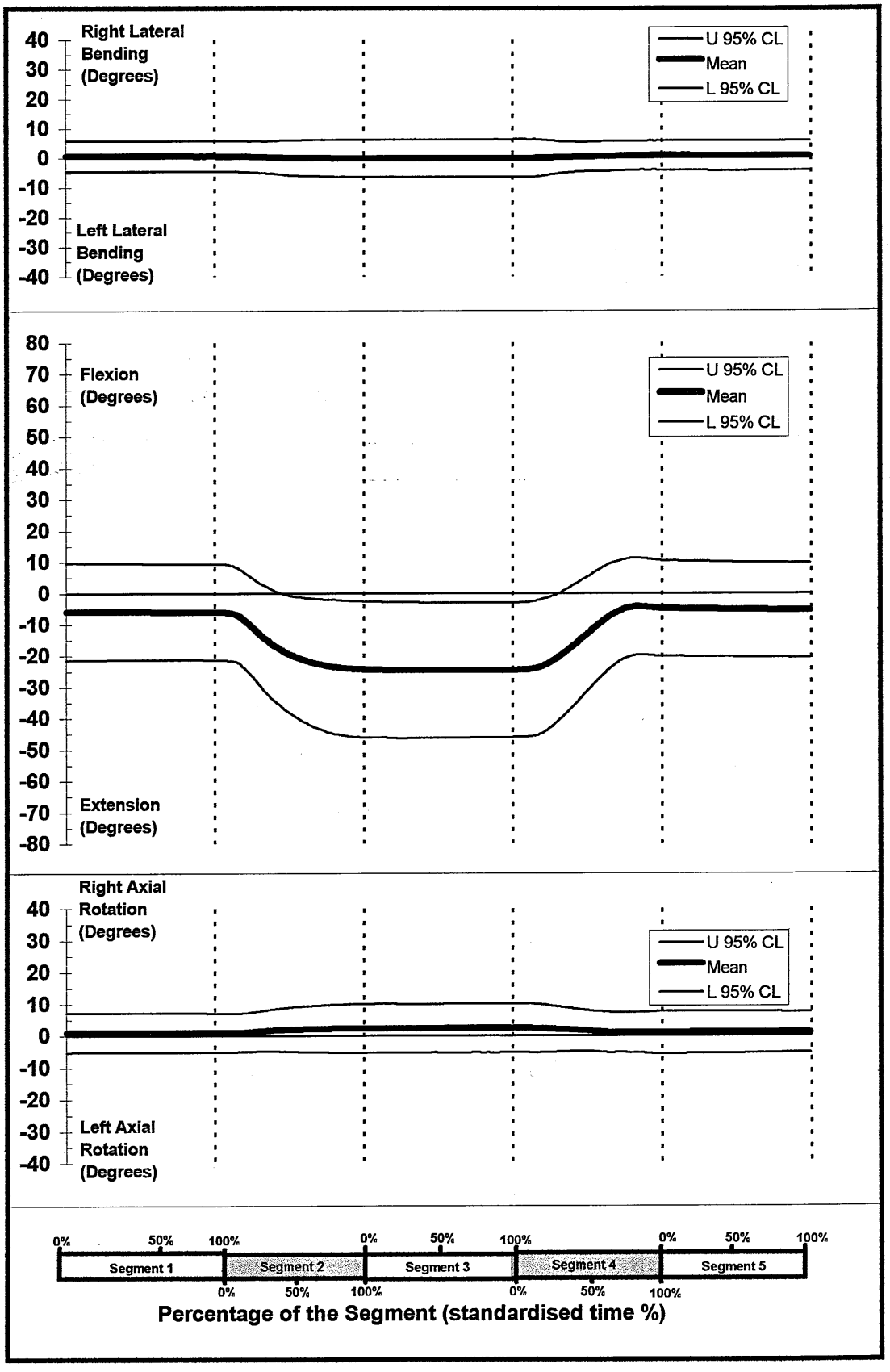


Figure 10.4 Interpolated mean plot of 100 healthy subjects performing extension in standing

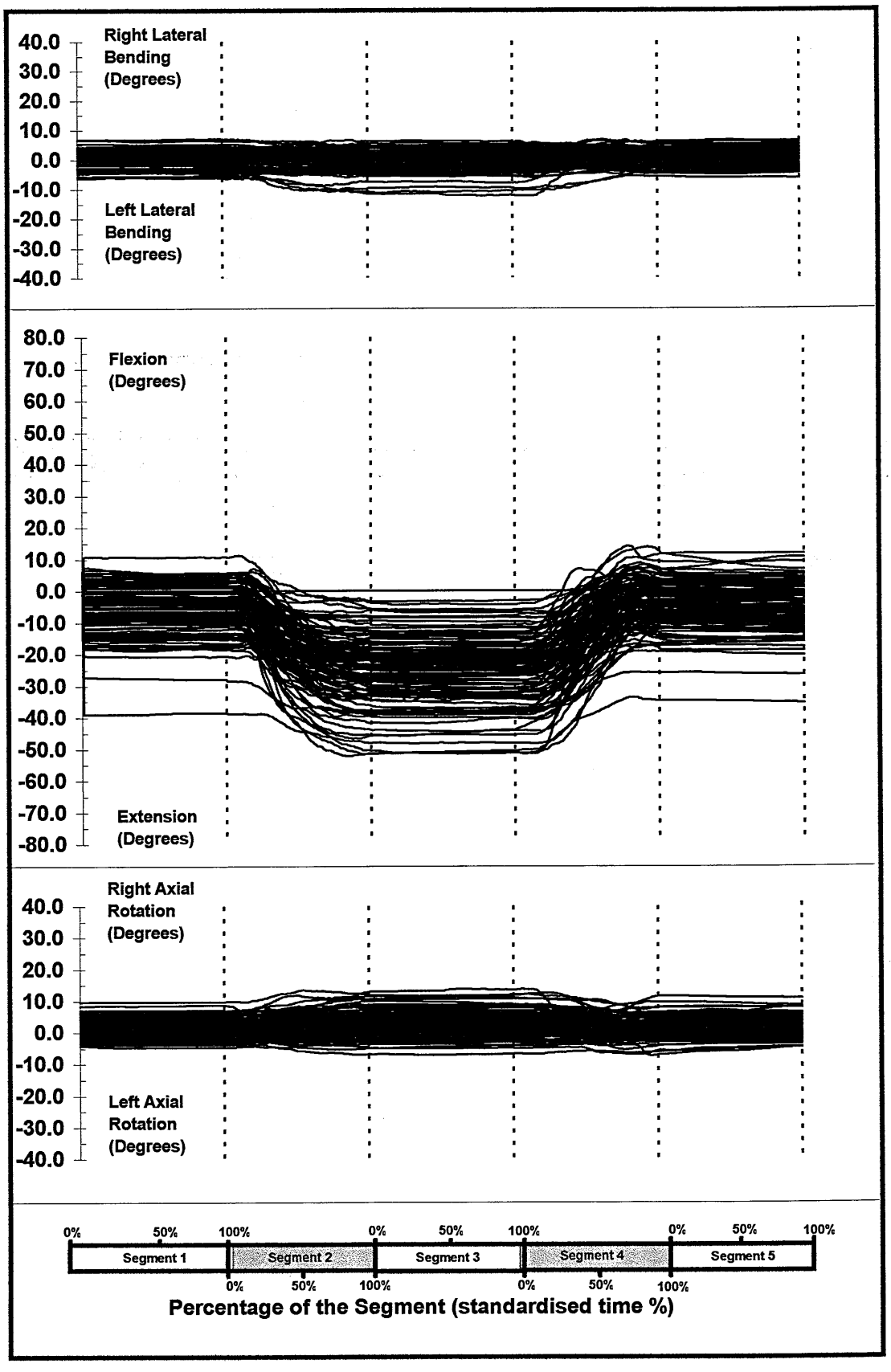


Figure 10.5 Interpolated Individual plots of 100 healthy subjects performing extension in standing

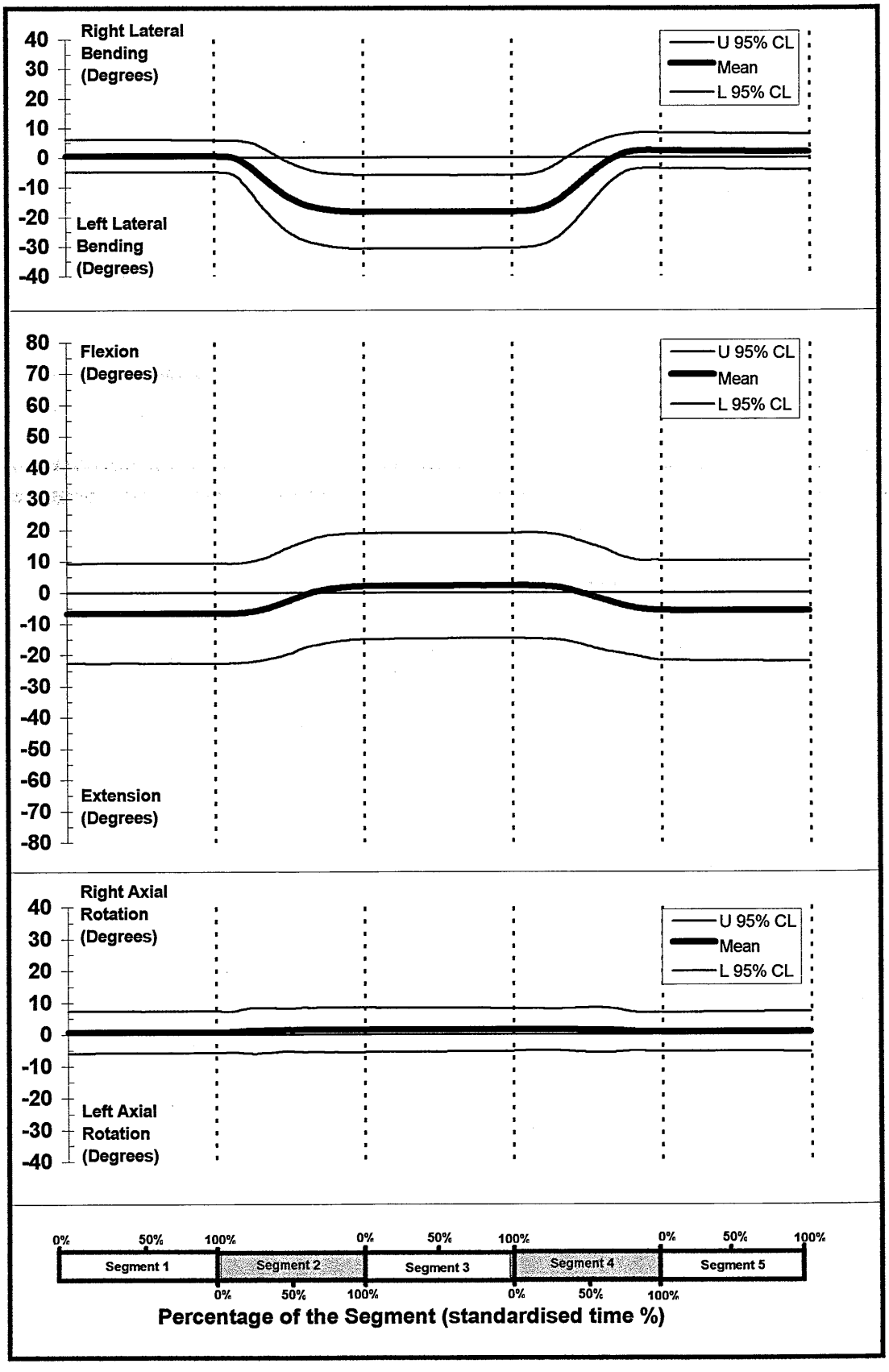


Figure 10.6 Interpolated mean plot of 100 healthy subjects performing left lateral bending in standing

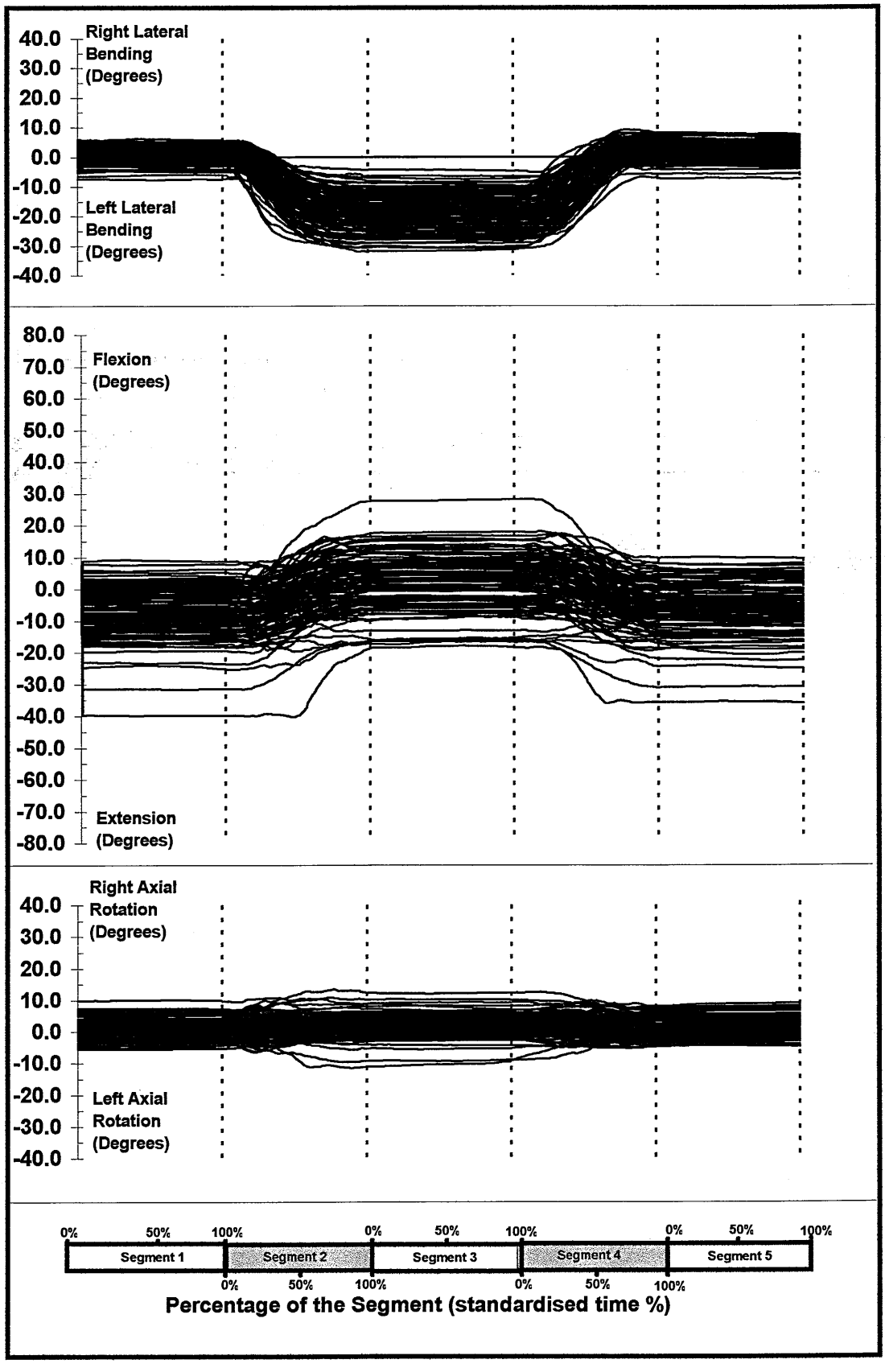


Figure 10.7 Interpolated Individual plots of 100 healthy subjects performing left lateral bending in standing

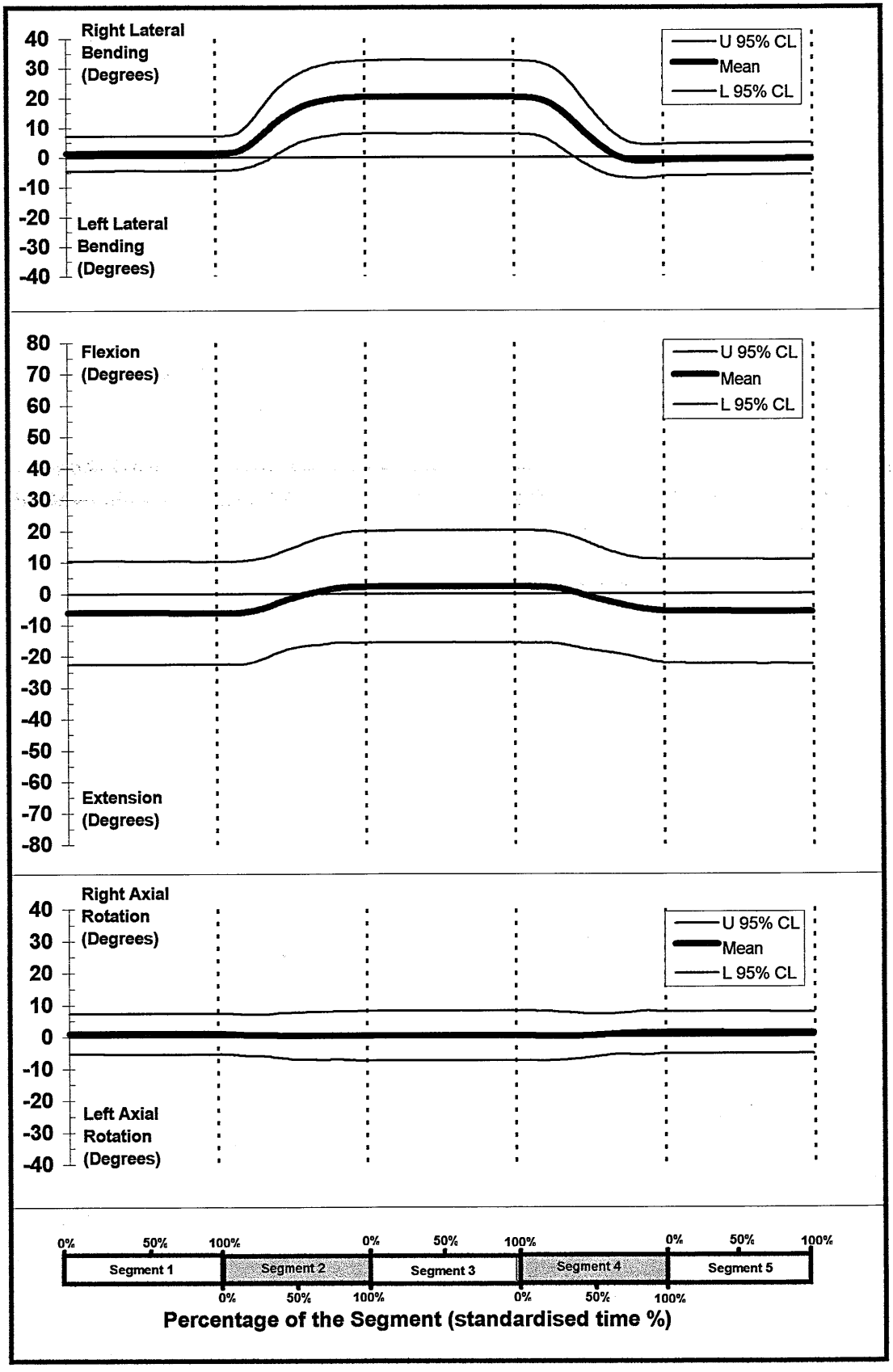


Figure 10.8 Interpolated mean plot of 100 healthy subjects performing right lateral bending in standing

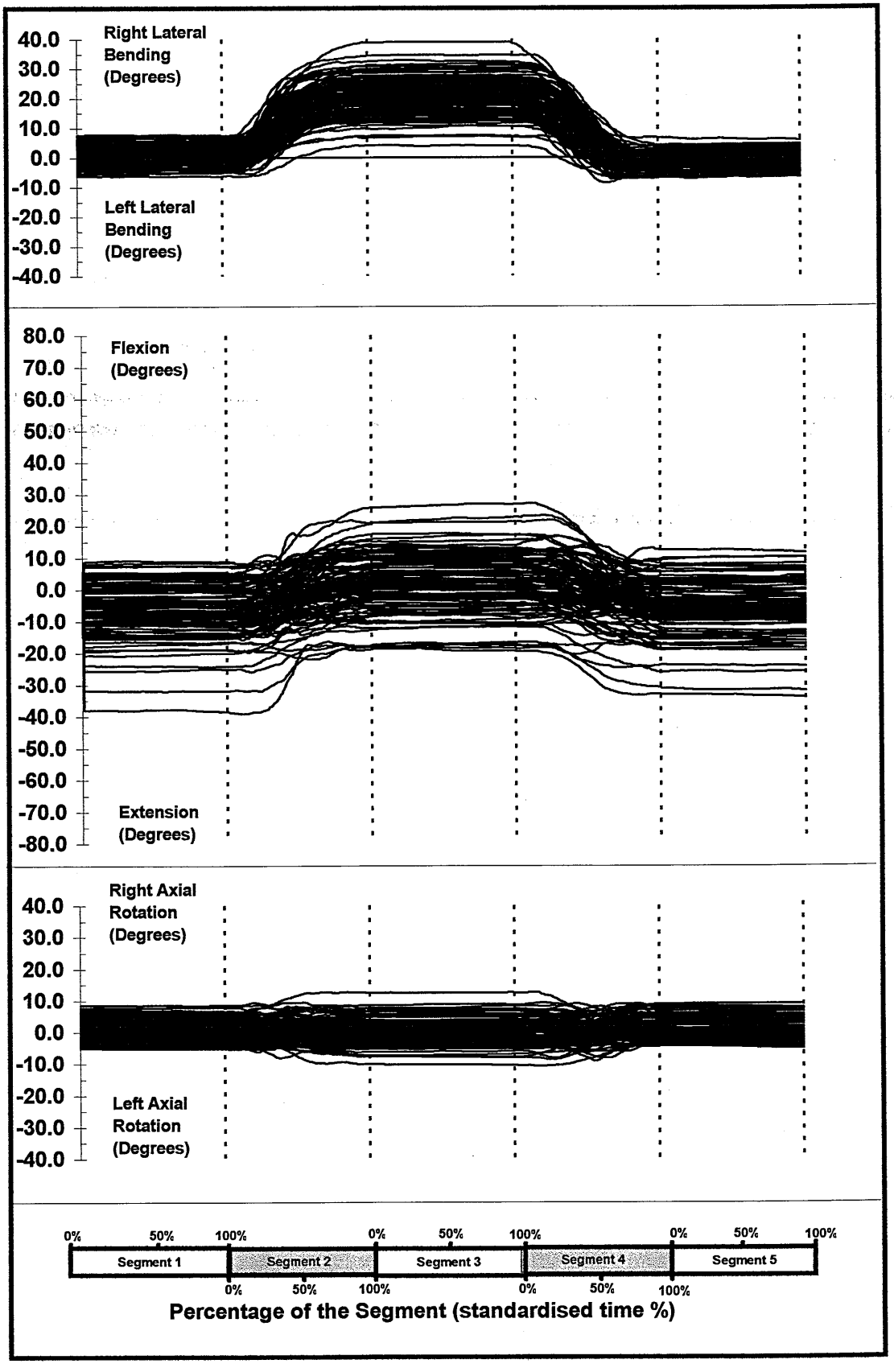


Figure 10.9 Interpolated Individual plots of 100 healthy subjects performing right lateral bending in standing

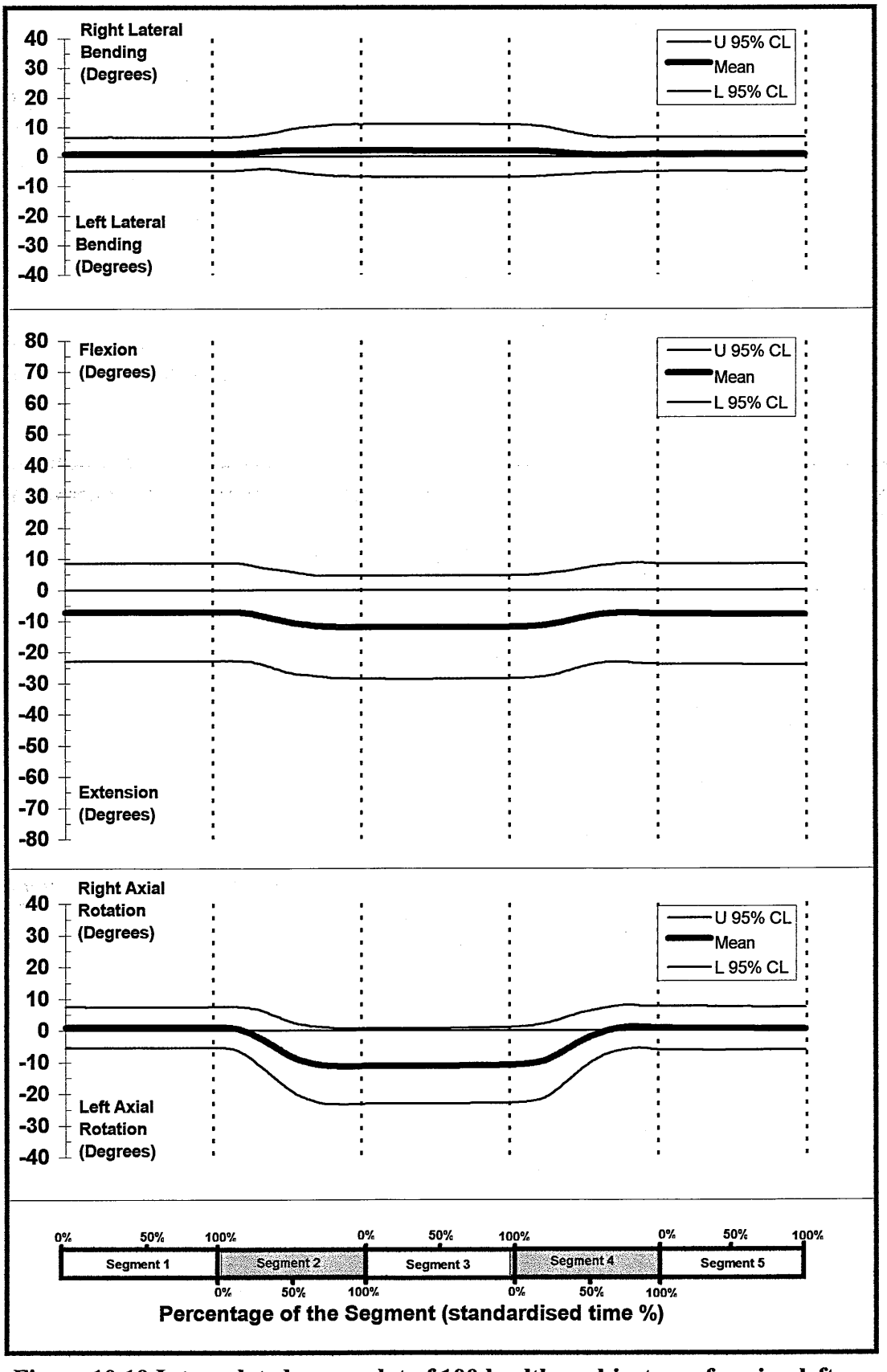


Figure 10.10 Interpolated mean plot of 100 healthy subjects performing left axial rotation in standing

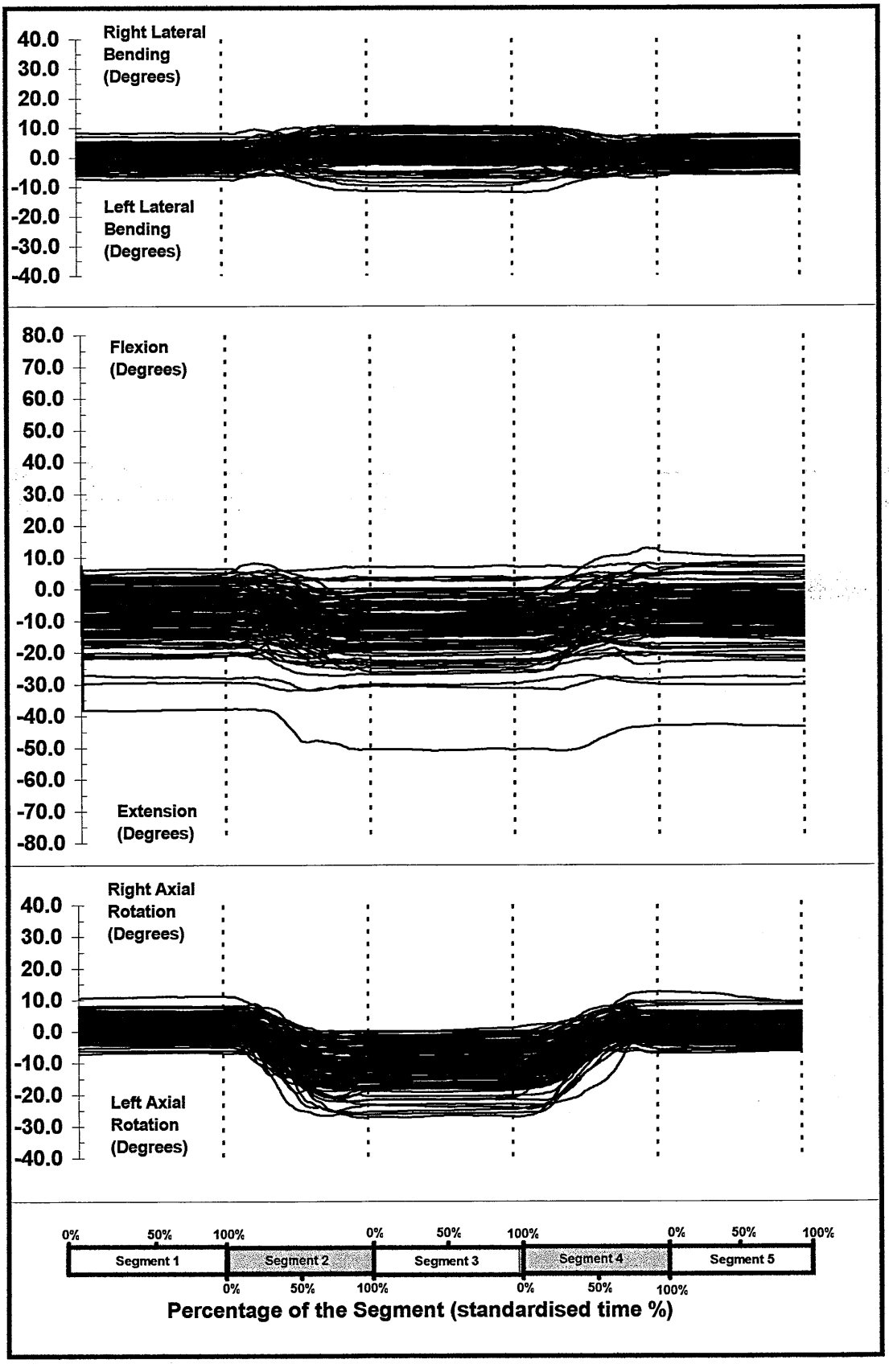


Figure 10.11 Interpolated Individual plots of 100 healthy subjects performing left axial rotation in standing

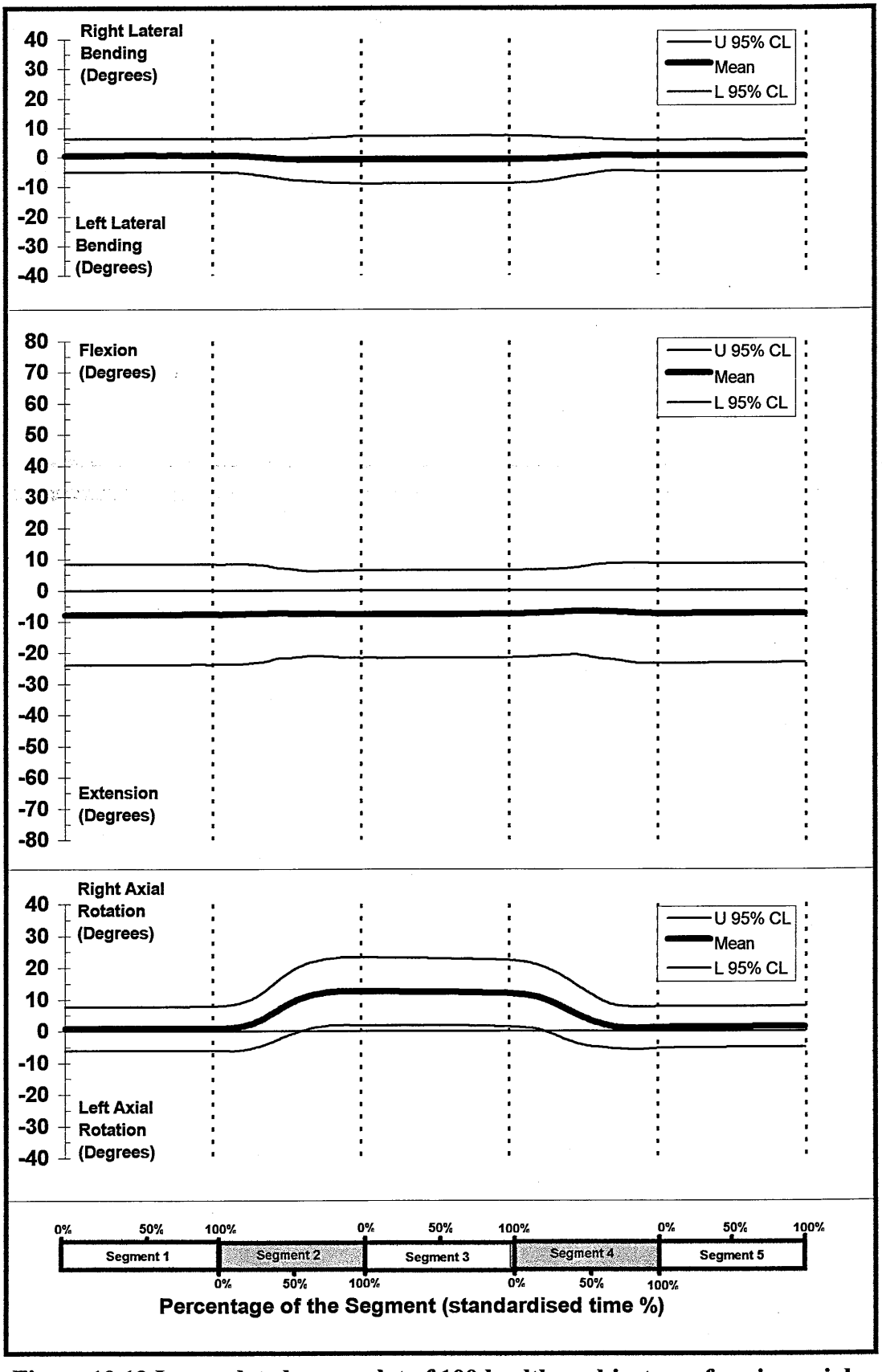


Figure 10.12 Interpolated mean plot of 100 healthy subjects performing axial rotation to the right in standing

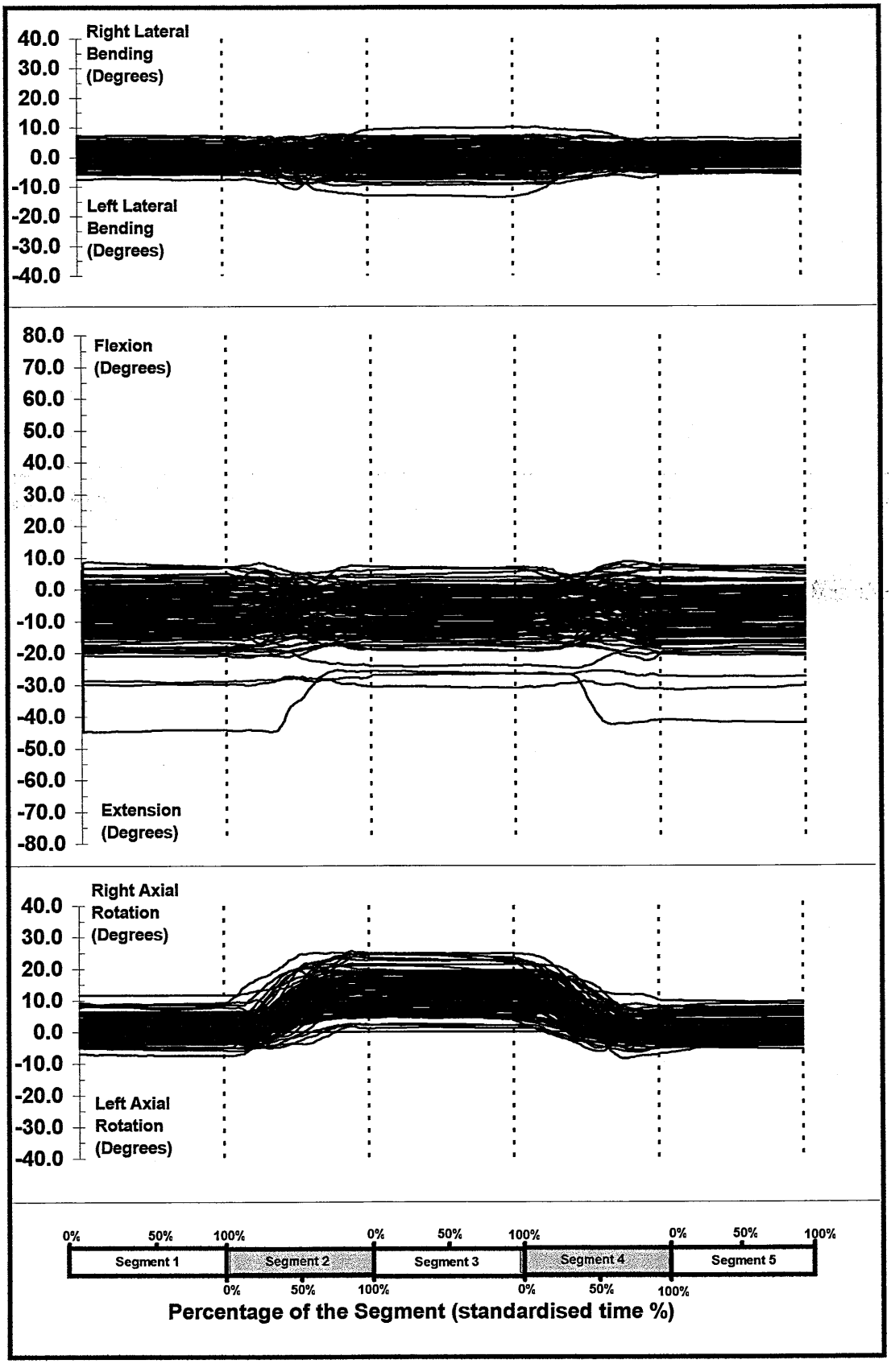


Figure 10.13 Interpolated individual plots of 100 healthy subjects performing axial rotation to the right in standing

From the different mean traces it can be observed that the movements were performed smoothly and without deviating into the opposite direction at the beginning of the movement i.e. the subject went from the neutral position of measurement i.e. standing, without an overshoot position (figure 10.14) to the maximum of the range of motion in that direction. Therefore, the difference between maximum and minimum in each direction reflects the true angular displacement used relative to the standing position i.e. the limit of the range of motion in that direction. The excursion of the joint during a given test is therefore reflected by this value

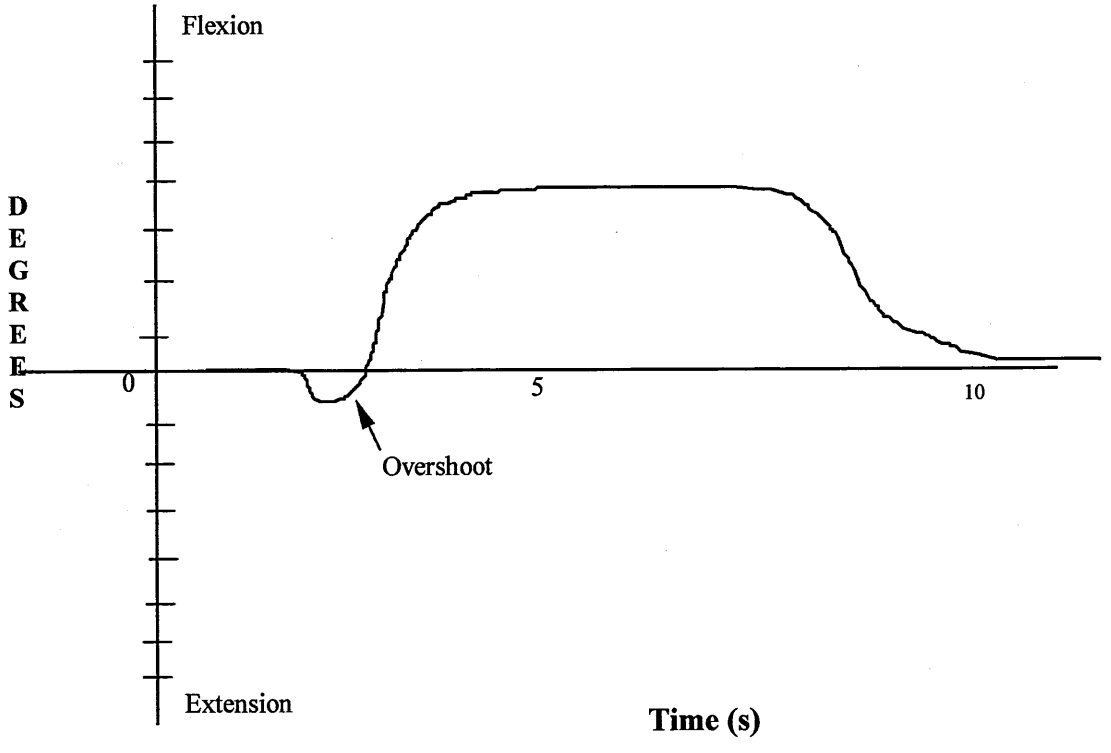


Figure 10.14 schematic representation of an overshoot phenomenon

10.2.2 Lumbar mobility excursion values in 6 gross movements (standing)

Coupled movements

In chapter 2 the phenomenon of coupling of lumbar intervertebral movement was discussed. From the main and individualised plots produced (figures 10.2-10.13) it was possible to

observe which movements were coupled with the primary movement and hence the pattern of movement that occurred.

In forward flexion (figures 10.2 and 10.3) no distinct coupling pattern emerged as the movements of lateral bending and axial rotation stayed close to zero degrees. It was also noticed that most of the subjects had more extension in standing (5 degrees) than in prone lying position (0 degrees) and they returned to the neutral standing position (5 degrees) after the movement was completed. No drift over time occurred as the movements were performed smoothly during the entire cycle. From the individual traces, a consistent pattern of movement with very few outliers could be observed.

In extension (figures 10.4 and 10.5) a slight but distinct coupling of extension (23.2 degrees) and right axial rotation (3.6 degrees) was noticed. As with flexion the starting position for extension was also noted to be slightly in extension (5 degrees) with the subjects returning to that position at the end of the movement. The lateral bending movement remained close to zero during the whole cycle. Occasional outliers were observed in the extension trace.

The primary movement of lateral bending to the left (figures 10.6 & 10.7) (21.7 degrees) was strongly coupled with flexion (12.1 degrees) and a simultaneously slight coupling of axial rotation to the right (4.7 degrees). A neutral position of 5 degrees of extension was again recorded at the start and end of the movements.

A similar pattern was observed in lateral bending to the right (figures 10.8 & 10.9). 22.9 degrees which was again strongly coupled with forward flexion (11.8) and with a simultaneously slight coupling of axial rotation to the left (5.0).

Both axial rotation to the left (14.0 degrees) and to the right (13.5) (figures 10.10 -10.13) were strongly coupled to extension (7.9 & 6.7 degrees respectively) and to a lesser extent to right and left lateral bend (5.0 & 4.7 degrees). Also for this movement a consistent 5 degrees of lumbar lordosis was noticed at the start and end of the movement.

Table 10.1 gives a summary of the kinematic patterns displayed by 100 healthy subjects during gross movements in standing.

Primary Movement	Excursion Values (Degrees)	Coupled Movements	Excursion Values (Degrees)	Percentage of main movement
Flexion	55.4 (9.1)	Lateral Bending	5.5 (2.1)	9.9%
		Axial Rotation	5.9 (2.8)	10.6%
Extension	23.2 (10.3)	Lateral Bending	3.0 (1.5)	12.9%
		Axial Rotation	3.6 (1.8)	15.5%
Left Lateral Bend	21.7 (6.4)	Flexion	12.1 (5.5)	55.5%
		Axial Rotation	4.7 (2.0)	22.6%
Right Lateral Bend	22.9 (6.6)	Flexion	11.8 (6.0)	51.5%
		Axial Rotation	5.0 (2.1)	21.8%
Left Axial Rotation	14.0 (5.5)	Extension	7.9 (4.3)	56.4%
		Lateral Bending	5.0 (2.5)	35.7%
Right Axial Rotation	13.5 (5.5)	Extension	6.7 (3.1)	49.6%
		Lateral bending	4.7 (2.0)	34.8%

Table 10.1 Summary of primary and coupled movements in 100 healthy subjects (All age groups, values in degrees, main excursion values (SD)

Main movements excursion values

Table 10.2 shows the excursions recorded for the primary movement during each of the six gross movements for all 100 healthy subjects.

Movement	All Subjects n=100 (Degrees)
Flexion	55.4 (9.1)
Extension.	23.1 (10.3)
Left Lateral Bend	21.7 (6.4)
Right Lateral Bend	22.9 (6.6)
Left Axial Rotation	14.0 (5.5)
Right Axial Rotation	13.5 (5.5)

Table 10.2 Comparison between mean rotation flexibility values in the healthy human spine (all age groups, values in degrees, Mean (SD)

Hence in the healthy adult spine, mobility, measured by a 3 dimensional electro-magnetic goniometer can be expected to give 55 degrees of flexion, 23 degrees of extension, 22 degrees lateral bending to the left, 22 degrees lateral bending to the right, 14 degrees rotation to the left and 14 degrees rotation to the right.

10.2.3 Effect of Age, Gender, Height and Mass on Lumbar Spinal Flexibility in standing.

In order to evaluate if age, gender, height and mass had an influence on lumbar mobility in healthy subjects single regression analysis was carried out for flexion, extension, lateral bending to the left, lateral bending to the right, axial rotation to the left and axial rotation to the right in standing.

The results of this analysis are shown in Tables 10.3 to 10.13

Flexion	Slope	Intercept	P-Value, Slope	P-Value, Intercept	Significance
Age	-0.118	60.8	0.044	<0.001	Yes
Gender	-0.747	55.8	0.684	<0.001	No
Height	0.096	39.0	0.376	0.037	No
Mass	0.047	52.0	0.546	<0.001	No

Table 10.3 Regression analysis of forward flexion

Extension	Slope	Intercept	P-Value, Slope	P-Value, Intercept	Significance
Age	0.315	-37.6	<0.001	<0.001	Yes
Gender	6.83	-26.6	<0.001	<0.001	Yes
Height	0.117	-43.1	0.337	0.040	No
Mass	0.208	-38.4	0.015	<0.001	Yes

Table 10.4 Regression analysis of lumbar extension

LLBend.	Slope	Intercept	P-Value, Slope	P-Value, Intercept	Significance
Age	0.187	-30.3	<0.001	<0.001	Yes
Gender	1.63	-22.5	= 0.204	<0.001	No
Height	-0.015	-19.1	0.84	0.145	No
Mass	0.152	-32.8	0.004	<0.001	Yes

Table 10.5 Regression analysis of lateral bend to the left

RLBend.	Slope	Intercept	P-Value, Slope	P-Value, Intercept	Significance
Age	-0.186	31.3	<0.001	<0.001	Yes
Gender	-1.577	23.6	0.236	<0.001	No
Height	0.012	20.9	0.883	0.125	No
Mass	-0.125	32.0	0.025	<0.001	Yes

Table 10.6 Regression analysis of lateral bend to the right

LAxRot.	Slope	Intercept	P-Value, Slope	P-Value, Intercept	Significance
Age	0.085	-17.9	0.016	<0.001	Yes
Gender	4.070	-16.1	<0.001	<0.001	Yes
Height	0.134	-36.8	0.040	= 0.001	Yes
Mass	0.134	-23.8	0.003	<0.001	Yes

Table 10.7 Regression analysis of axial rotation to the left

RAxRot.	Slope	Intercept	P-Value, Slope	P-Value, Intercept	Significance
Age	-0.023	14.6	0.519	<0.001	No
Gender	-2.829	14.9	0.010	0.009	Yes
Height	-0.086	28.1	0.194	0.013	No
Mass	-0.092	20.2	0.048	<0.001	Yes

LLBend. = Left Lateral Bending RLBend. = Right Lateral Bending LAxRot. = Left Axial Rotation RAxRot.= Right Axial Rotation

Table 10.8 Regression analysis of axial rotation to the right

The results demonstrate that age has a significant influence on mobility in the lumbar spine. for 5 of the 6 gross movements. Gender was significantly related to axial rotation and extension but not lateral bending and flexion. For height there was only a weak but significant relationship for axial rotation to the left. Mass was significantly related to lumbar flexibility in 4 out of the 6 movements. Only for flexion and left lateral bending were no significant influences with mass found.

10.2.4 Differences in Lumbar Excursion between Gender Cohorts measured from a standing position

Table 10.14 shows the mean excursion recorded in each of the six gross movements for 50 female and 50 male subjects.

Movement	Females n=50	Males n=50
Flexion	55.8 (9.5)	55.1 (8.8)
Extension.	26.6 (11.5)	19.7(7.5)
Left Lateral Bending	22.5 (5.4)	20.9 (7.2)
Right Lateral Bending	23.6 (6.0)	22.1 (7.2)
Left Axial Rotation	16.1 (5.9)	12.0 (4.2)
Right Axial Rotation	14.9 (5.6)	12.1 (5.1)

Table 10.9 Mean excursions for gross movements in standing for 50 healthy female and 50 male subjects (values in degrees).

The female subjects exhibited greater joint mobility in all six directions when compared to their male counterparts although forward flexion was nearly equal in both groups (table 10.14).

The differences in excursion between gender cohorts where tested for statistical significance. A two tailed t-test for independent samples with equal variances was used after testing the distributions for normality. The results are summarised in table 10.10.

Movement	t-test for independent samples 2 tailed significance and 95% confidence interval
Flexion	NS, = 0.684, (-2.89 degrees, 4.38 degrees)
Extension.	F>M, p = 0.001, (2.97 degrees, 10.68 degrees)
Left Lateral Bending	NS, p = 0.204, (-0.89 degrees, 4.15 degrees)
Right Lateral Bending	NS, p = 0.236, (-1.04 degrees, 4.20 degrees)
Left Axial Rotation	F>M, p = 0.000, (2.03 degrees, 6.11 degrees)
Right Axial Rotation	F>M, p = 0.010, (0.69 degrees, 4.95 degrees)

NS= Non Significant F=female M=Male

Table 10.10 Significance testing for Gender Differences in RoM (Degrees)

Females showed a significantly greater mobility in extension (p = 0.001) and left (p = 0.000) and right (p = 0.010) axial rotation. Although greater values were also recorded for females in the other directions these did not reach the chosen significance level (p = 0.05).

10.2.5 Differences in Lumbar Excursion in standing between Age Cohorts given Gender (measured in standing)

Table 10.11 displays the results broken down by gender and age category.

Movement	Female					Male				
Age / Movement	20-29	30-39	40-49	50-59	60+	20-29	30-39	40-49	50-59	60+
Flexion	58.9	58.2	57.5	53.6	50.8	56.4	54.2	54.2	58.1	52.3
	(10.5)	(6.9)	(10.2)	(11.4)	(6.6)	(7.1)	(9.6)	(8.9)	(10.6)	(8.2)
Extension	37.0	31.2	29.0	20.5	15.1	22.5	22.1	20.0	17.2	16.9
	(10.5)	(11.7)	(8.5)	(6.1)	(5.2)	(7.8)	(9.5)	(6.1)	(7.2)	(5.6)
Left LB	25.1	25.6	20.7	21.9	19.4	25.8	25.6	19.3	19.0	14.6
	(2.8)	(5.6)	(3.6)	(6.2)	(6.1)	(7.6)	(5.4)	(6.2)	(5.80	(4.6)
Right LB	26.3	26.2	23.4	23.2	19.2	26.2	25.0	21.2	22.4	15.5
	(4.3)	(7.2)	(4.7)	(5.7)	(5.6)	(8.4)	(5.0)	(7.0)	(6.4)	(4.3)
Left Ax.Rot.	18.6	18.0	15.7	14.7	14.7	14.4	11.9	11.6	11.3	10.9
	(5.8)	(6.2)	(4.2)	(6.1)	(6.5)	(5.1)	(3.2)	(4.9)	(3.8)	(3.9)
Right.Ax.Rot.	18.6	15.6	13.4	14.2	13.0	12.8	9.1	12.7	11.3	14.6
	(4.9)	(6.2)	(3.8)	(6.0)	(6.0)	(4.1)	(4.5)	(5.7)	(4.3)	(6.0)

Left LB = Left Lateral Bending
Right LB.= Right Lateral Bending
Left Ax.Rot.= Left Axial Rotation
RightAx.Rot.= Right Axial Rotation

Table 10.11 The mean, maximal rotational movement displayed by all ten subjects in 5 different age cohorts for males and females (all values in degrees).

In the majority of age cohorts females can be seen to exhibit a greater joint mobility, in each of the six directions, than their male counterparts, indicating that females are generally more flexible throughout the age range tested.

A general trend of reducing motion with age in both males and females can be observed from Table 10.11. A consistent reduction in motion is seen in each decade age group for all movements except for flexion in the male 50-59 age group and right axial rotation in the male 60+ group where there appears to be an increase in value. Furthermore, an increase in

right axial rotation mobility was observed in the male cohort where the oldest cohort displayed higher values then the younger age groups

Statistical significance testing was carried out between the youngest (20-29) age group and the oldest (60+) age group in order to confirm the general trend.

Movement	t-test for independent samples 2 tailed significance and 95% confidence interval
Flexion	Y>O, p = 0.022, (0.94 degrees, 11.30 degrees)
Extension.	Y>O, p = 0.000, (7.98 degrees, 19.59 degrees)
Left Lateral Bend	Y>O, p = 0.000, (4.80 degrees, 12.08 degrees)
Right Lateral Bend	Y>O, p = 0.000, (5.08 degrees, 12.64 degrees)
Left Axial Rotation	Y>O, p = 0.020, (0.70 degrees, 7.82 degrees)
Right Axial Rotation	NS, p = 0.297, (-1.71 degrees, 5.45 degrees)

Table 10.12 Analysis of differences in excursions (Degrees) between Young (20-30 years) and Old (60+) Age groups.

Two tailed t-test for independent samples with equal variance between the youngest (20-30 age) and the oldest age group (60+) confirms the trend of decreasing movement with advancing age. This was true for all movements, although in axial rotation to the right it did not reach statistical significance,(p = 0.297), (Table 10.12).

10.2.6 Lumbar flexibility in gross movements measured from a sitting position

The position of lumbar spinal mobility assessment in the clinic varies among the authors of different textbooks in orthopaedic manual therapy. Most textbooks recommend the standing position for recording flexion, extension and lateral bending. However most textbooks recommend that axial rotation is measured in the sitting position in order to stabilise the

pelvis. Table 10.13 provides an overview over the most common textbook used in physiotherapy schools in the UK.

Author	Standing	Sitting	Remarks
1. Maitland 1986	Flexion, Extension, Axial Rotation, Lateral. bend		
2. Maggee, 1987	Flexion Extension, Lateral.bend Axial Rotations	Axial rotations in sitting recommended	Hands at small of back to eliminate hip movements
3. McRae, 1983	Flexion, Extension, Lateral Bend	Axial Rotations	Hands not crossed , tape measure
4. Hoppenfeld, 1986	Flexion, Extension, Lateral. bend , Axial rotations		Stabilised iliac crest.
5. Kaltenborn & Evjent, 1989	Flexion, Extension, Lateral bend	Axial Rotation flexion & extension	arms crossed in front
6. Stoddard, 1959 last new print 1978	Lateral bending,	Flexion , extension Axial rotation,	Flexion in sidelying
7. Grieve, 1984	Flexion, Extension, Lateral bend,	Axial rotations	Knees together and arms folded
8. Jull in Grieve, 1986	Flexion, Extension, Axial rotations, Lateral bend		
9. Cyriax, 1984	Extension, Lateral. bend, Flexion		No rotations
10. Hughes et al 1987	Flexion, Lateral. bend, Axial rotation		Rotation with stabilisation
11. Gerard & Kleinfeld, 1993	Flexion, Extension Axial Rotations, Lateral. bend		No stabilisation

Table 10.13 Overview of different authors, recommendations for measuring lumbar spinal motion

Table 10.14 gives an overview of the differences in mean excursion ranges between recordings in standing and sitting position. The null hypothesis of no difference between the tests performed in standing and in sitting was tested using a 2-way, paired samples t-test (equal variances).

Movement	Mean Excursion in Standing °	Mean Excursion in Sitting °	Significance p-value	95% Confidence Interval
Flexion	55.4	41.6	$p < 0.001$	(11.9, 15.5)
Extension.	23.1	26.1	$p = 0.008$	(-5.1, -0.7)
Left Lateral Bend	21.7	23.8	$p < 0.001$	(1.2, 2.9)
Right Lateral Bend	22.9	25.2	$p < 0.001$	(1.6, 3.2)
Left Axial Rotation	14.0	18.7	$p < 0.001$	(3.8, 5.4)
Right Axial Rotation	13.6	18.7	$p < 0.001$	(4.3. 5.8)

Table 10.14 Differences in lumbar spinal mobility recorded in standing and sitting (degrees)

Significant differences ($p<0.05$) were recorded between measurements in the standing position and recordings in the sitting position for all six cases. The highest values were consistently recorded in the sitting position except for forward flexion which scored significantly lower values in sitting. However, a sitting position will always prevent the lumbar spine flexing maximally due to the obstructive nature of the abdominal mass. Recording lumbar extension from a sitting position is known to put a lot a strain on the abdominal muscles. Further, in order to keep a balanced position, it is not possible for maximal extension to be developed by the subjects.

The recording of lateral bending and axial rotation from a sitting position should be avoided because these positions are known to allow the spine to move to its maximum limit and hence are potentially hazardous for low back pain patients (Hindle and Pearcy, 1989). In addition, the standing position was used in most reported studies on 3 dimensional lumbar motion and therefore preferable in order to enable us to compare the results obtained with similar studies reported in the literature.

For all these reasons, in this study gross movements were subsequently analysed only in standing and these standing values were used to evaluate the results of the randomised controlled trial.

10.2.7 Database

A database for all 100 healthy subjects displaying the mean excursion values was established for the 6 gross movements in standing in order to compare and contrast patients values. These values are represented in tables 10.15 to 10.20.

Table 10.15 Database for 3 Dimensional Mobility of the Lumbar Spine measured by the 3 Space Isotrak Forward Flexion in Standing-Degrees

		Females						Males					
Age Cohort (Years)	**All**	**All**	**20**	**30**	**40**	**50**	**60**	**All**	**20**	**30**	**40**	**50**	**60**
n =	**100**	**50**	**10**	**10**	**10**	**10**	**10**	**50**	**10**	**10**	**10**	**10**	**10**
Mean	55.4	55.8	58.9	58.2	57.5	53.6	50.8	55.1	56.4	54.2	54.2	58.1	52.3
SD	9.1	9.5	10.5	6.9	10.2	11.4	6.6	8.8	7.1	9.6	8.9	10.6	8.2
Upp. 95% Conf.Limit	73.3	74.4	79.6	71.8	77.6	75.9	63.1	72.3	70.3	73.0	71.7	78.9	68.3
Low. 95% Conf. Limit	37.6	37.2	38.3	44.5	37.5	31.3	37.8	37.8	42.6	35.5	36.7	37.3	36.3
Maximum	76.4	76.4	76.4	71.9	73.6	71.0	63.0	74.6	66.7	67.1	67.3	74.6	61.7
Minimum	35.7	37.5	49.2	49.7	42.1	37.5	41.3	35.7	45.7	39.3	35.7	43.7	36.3
Median	55.0	54.8	54.1	58.2	58.2	56.7	48.5	55.2	55.4	53.0	55.4	58.2	53.8
97.5 Percentile	73.5	73.6	75.8	70.3	72.9	69.1	62.3	71.3	66.4	66.7	66.7	74.1	61.4
2.5 Percentile	38.1	39.4	49.2	49.9	42.7	37.8	42.5	37.0	46.5	40.5	38.6	43.8	37.6

Table 10.16 Database for 3 Dimensional Mobility of the Lumbar Spine measured by the 3 Space Isotrak Extension in Standing - Degrees

		Females						Males					
Age Cohort (Years)	**All**	**All**	**20**	**30**	**40**	**50**	**60**	**All**	**20**	**30**	**40**	**50**	**60**
n =	**100**	**50**	**10**	**10**	**10**	**10**	**10**	**50**	**10**	**10**	**10**	**10**	**10**
Mean	23.2	26.6	37.0	31.2	29.0	20.5	15.1	19.7	22.5	22.1	20.0	17.2	16.9
SD	10.3	11.5	10.5	11.7	8.5	6.1	5.2	7.5	7.8	9.5	6.1	7.2	5.6
Upp. 95% Conf.Limit	43.2	49.2	57.5	54.2	45.7	32.5	25.2	34.3	37.7	40.6	32.0	31.4	28.0
Low. 95% Conf. Limit	3.1	4.0	16.5	8.3	12.2	8.4	4.9	5.1	7.3	3.5	7.9	3.0	5.9
Maximum	53.8	53.8	53.2	53.8	39.7	31.9	25.2	37.4	33.3	37.4	29.0	27.9	28.4
Minimum	7.3	8.3	15.1	19.0	16.1	12.0	8.3	7.3	10.7	7.9	11.1	7.3	10.7
Median	21.1	23.1	35.9	29.2	30.8	19.0	14.0	18.5	22.7	19.3	21.0	15.4	15.2
97.5 Percentile	46.7	52.2	52.2	51.0	39.4	30.7	24.2	33.0	32.9	36.2	28.1	27.4	27.4
2.5 Percentile	8.8	9.9	19.0	19.0	17.0	12.3	8.5	8.3	11.1	9.1	11.4	7.9	10.9

Table 10.17 Database for 3 Dimensional Mobility of the Lumbar Spine measured by the 3 Space Isotrak Left Lateral Bending in Standing - Degrees

		Females						Males					
Age Cohort (Years)	**All**	**All**	**20**	**30**	**40**	**50**	**60**	**All**	**20**	**30**	**40**	**50**	**60**
n =	**100**	**50**	**10**	**10**	**10**	**10**	**10**	**50**	**10**	**10**	**10**	**10**	**10**
Mean	21.7	22.5	25.1	25.6	20.7	13.1	19.4	20.9	25.8	25.6	19.3	19.0	14.6
SD	6.4	5.4	2.8	5.6	3.6	6.2	6.1	7.2	7.6	5.4	6.2	5.8	4.6
Upp. 95% Conf.Limit	34.2	33.1	30.6	36.5	27.7	25.3	31.3	35.0	40.6	36.2	31.6	30.5	23.7
Low. 95% Conf. Limit	9.2	11.9	19.6	14.6	13.6	0.9	7.4	6.8	10.9	15.1	7.1	7.6	5.6
Maximum	35.7	33.8	29.4	33.8	26.5	22.7	28.8	35.7	34.5	35.7	29.2	30.0	21.1
Minimum	6.6	7.3	20.8	14.5	13.2	4.4	7.3	6.6	14.5	19.6	11.8	9.0	6.6
Median	21.4	22.5	25.2	26.5	21.0	12.1	20.6	20.1	27.5	25.6	16.5	18.2	15.1
97.5 Percentile	33.4	32.5	29.1	33.2	25.7	22.3	27.8	34.1	34.1	35.1	28.3	28.6	20.7
2.5 Percentile	8.1	12.4	21.1	15.9	14.3	4.9	8.4	7.6	14.6	19.8	12.1	9.9	6.8

Table 10.18 Database for 3 Dimensional Mobility of the Lumbar Spine measured by the 3 Space Isotrak Right Lateral Bending in Standing - (Degrees)

		Females						Males					
Age Cohort (Years)	**All**	**All**	**20**	**30**	**40**	**50**	**60**	**All**	**20**	**30**	**40**	**50**	**60**
n =	**100**	**50**	**10**	**10**	**10**	**10**	**10**	**50**	**10**	**10**	**10**	**10**	**10**
Mean	22.9	23.6	26.3	26.2	23.4	23.2	19.2	22.1	26.2	25.0	21.1	22.4	15.5
SD	6.6	6.0	4.3	7.2	4.7	5.7	5.6	7.2	8.4	5.0	7.0	6.4	4.3
Upp. 95% Conf.Limit	35.8	35.3	34.8	40.3	32.6	34.3	30.2	36.2	42.7	34.9	35.0	34.9	24.0
Low. 95% Conf. Limit	9.9	12.0	17.7	12.0	14.2	12.1	8.3	7.9	9.7	15.2	7.4	9.8	7.0
Maximum	40.9	40.9	33.5	40.9	29.4	32.6	30.1	40.1	40.1	33.4	37.8	34.4	23.6
Minimum	8.4	10.7	22.0	16.3	14.8	13.6	10.7	8.4	14.7	18.3	14.7	10.9	8.4
Median	22.8	23.3	23.9	25.3	24.0	23.1	19.0	20.9	27.1	24.7	19.4	22.1	15.3
97.5 Percentile	37.6	33.3	33.1	38.9	29.3	31.4	28.8	37.7	39.5	32.6	35.6	33.0	22.7
2.5 Percentile	11.0	13.5	22.2	16.6	15.7	14.1	11.3	11.0	14.8	18.4	14.8	12.0	9.0

Table 10.19 Database for 3 Dimensional Mobility of the Lumbar Spine measured by the 3 Space Isotrak Left Axial Rotation in Standing - Degrees

		Females						Males					
Age Cohort (Years)	**All**	**All**	**20**	**30**	**40**	**50**	**60**	**All**	**20**	**30**	**40**	**50**	**60**
n =	**100**	**50**	**10**	**10**	**10**	**10**	**10**	**50**	**10**	**10**	**10**	**10**	**10**
Mean	14.0	16.1	18.6	18.0	15.7	14.7	13.5	12.0	14.4	11.9	11.6	11.3	10.9
SD	5.5	5.9	5.8	6.2	4.2	6.1	6.5	4.2	5.1	3.2	4.9	3.8	3.9
Upp. 95% Conf.Limit	24.8	27.7	29.9	30.1	23.9	26.7	23.3	2.03	24.3	18.2	21.2	18.6	18.6
Low. 95% Conf. Limit	3.3	4.5	7.2	5.9	7.4	2.7	0.7	3.7	4.4	5.7	2.1	3.9	3.2
Maximum	29.7	29.7	26.9	26.7	20.9	22.8	25.3	22.8	22.8	16.8	19.9	17.3	15.7
Minimum	4.1	4.5	8.6	10.6	6.4	4.5	5.3	4.1	6.4	7.0	7.1	4.5	4.1
Median	13.5	15.6	18.2	16.4	15.7	15.6	12.6	12.4	14.6	12.7	9.0	11.4	11.9
97.5 Percentile	25.7	26.7	26.7	28.6	20.7	22.5	24.2	19.8	22.1	16.4	19.8	16.9	15.6
2.5 Percentile	4.9	5.4	9.6	11.1	7.9	5.2	5.4	4.7	6.6	7.1	7.1	5.0	4.4

Table 10. 20 Database for 3 Dimensional Mobility of the Lumbar Spine measured by the 3 Space Isotrak Right Axial Rotation in Standing - Degrees

		Females						Males					
Age Cohort (Years)	**All**	**All**	**20**	**30**	**40**	**50**	**60**	**All**	**20**	**30**	**40**	**50**	**60**
n =	**100**	**50**	**10**	**10**	**10**	**10**	**10**	**50**	**10**	**10**	**10**	**10**	**10**
Mean	13.5	14.9	18.6	15.6	13.4	14.2	13.0	12.1	12.8	9.1	12.7	11.3	14.7
SD	5.5	5.6	4.9	6.2	3.8	6.0	6.0	5.1	4.1	4.5	5.7	4.3	6.0
Upp. 95% Conf.Limit	24.4	25.9	28.1	27.7	20.8	25.9	24.7	22.1	20.9	17.8	23.9	19.6	26.4
Low. 95% Conf. Limit	2.7	4.0	9.0	3.5	5.9	2.5	1.3	2.1	4.7	0.4	1.4	2.9	3.0
Maximum	28.8	28.3	26.0	28.3	20.5	25.2	23.5	28.8	21.5	17.3	27.9	17.5	28.8
Minimum	2.5	4.3	10.5	8.5	5.6	5.4	4.3	2.5	8.4	2.5	8.1	5.6	8.6
Median	12.5	14.7	20.2	14.2	13.0	13.9	13.0	10.9	13.2	8.8	10.9	11.9	14.3
97.5 Percentile	27.0	25.8	25.0	27.1	19.4	23.9	22.2	26.5	20.1	16.7	25.1	17.2	23.3
2.5 Percentile	5.2	5.2	10.8	8.8	6.9	6.2	4.5	5.3	8.4	3.1	8.2	5.8	8.9

10.3 Analysis of 4 functional movements in 100 healthy subjects.

The 3 dimensional recording of lumbar spinal movements during the functional movements of sitting down and standing up from a stool, going up and down a step and picking up a box and putting it down on the left and picking up a box at the right and putting it down at the left are displayed in figures 10.26 to 10.33.

10.3.1 Lumbar mobility excursion plots in 100 healthy subjects

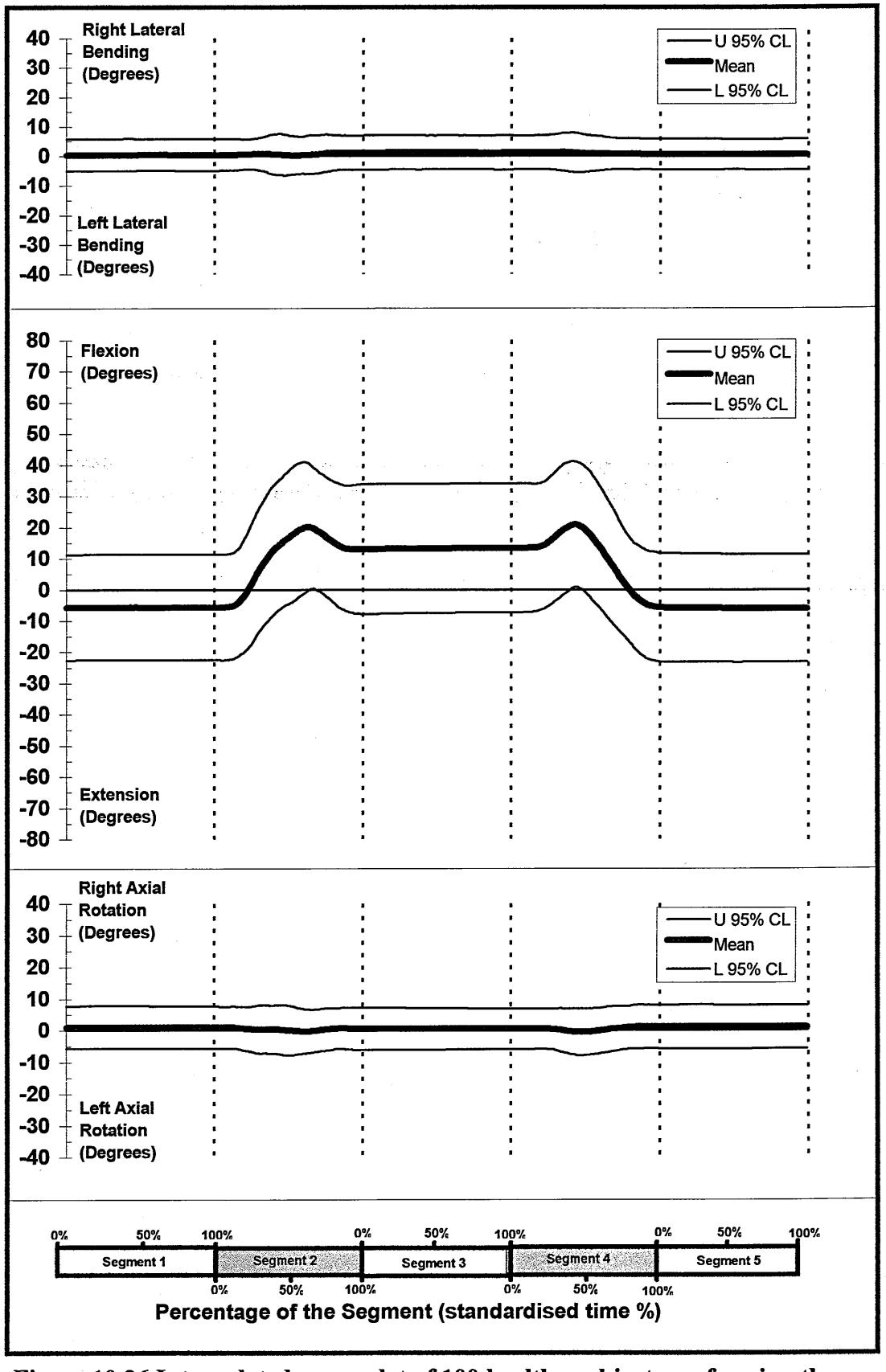


Figure 10.26 Interpolated mean plot of 100 healthy subjects performing the functional movement of sitting down and standing up from a stool.

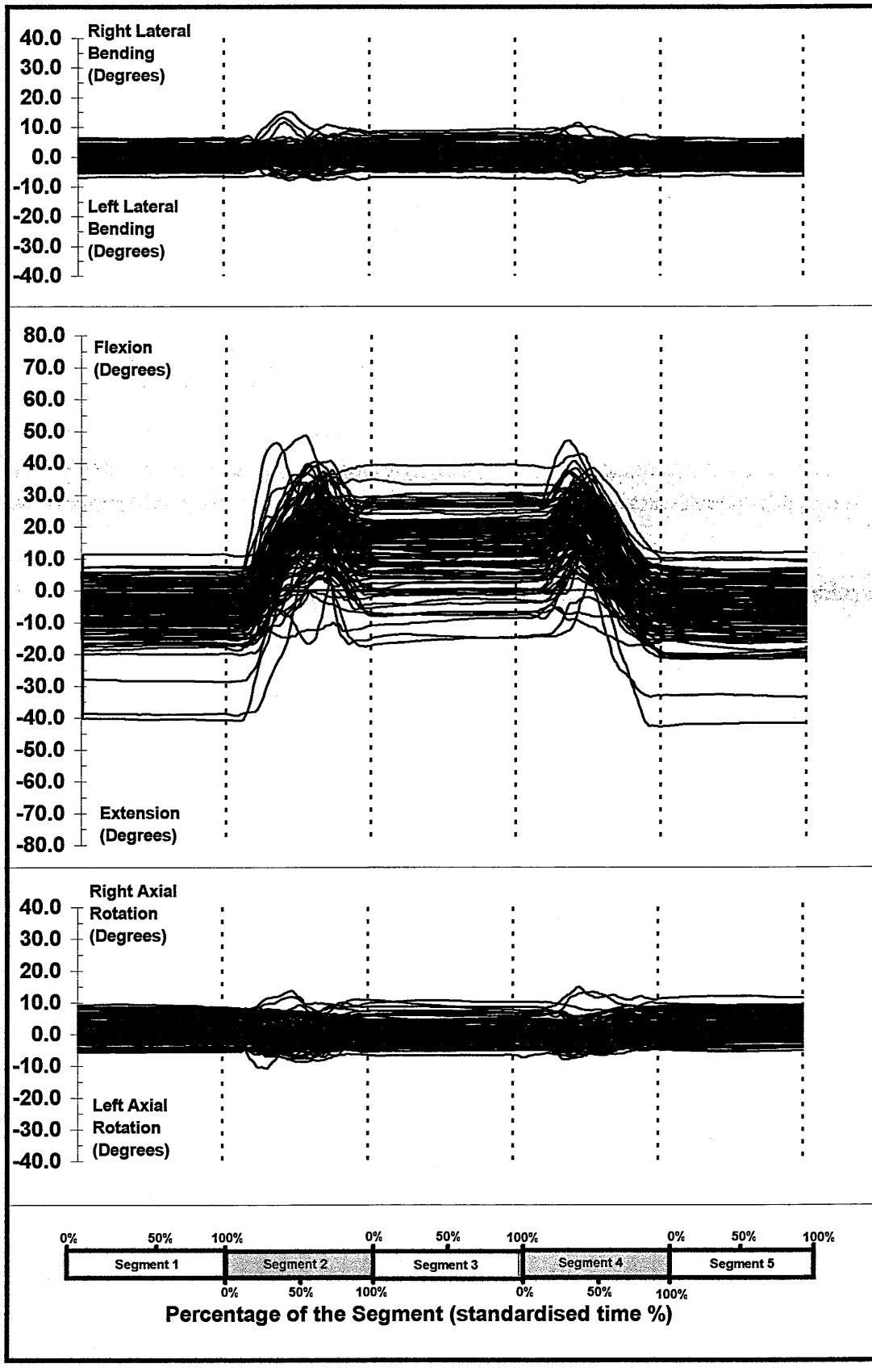


Figure 10.27 Interpolated individual plots of 100 healthy subjects performing the functional movement of sitting down and standing up from a stool.

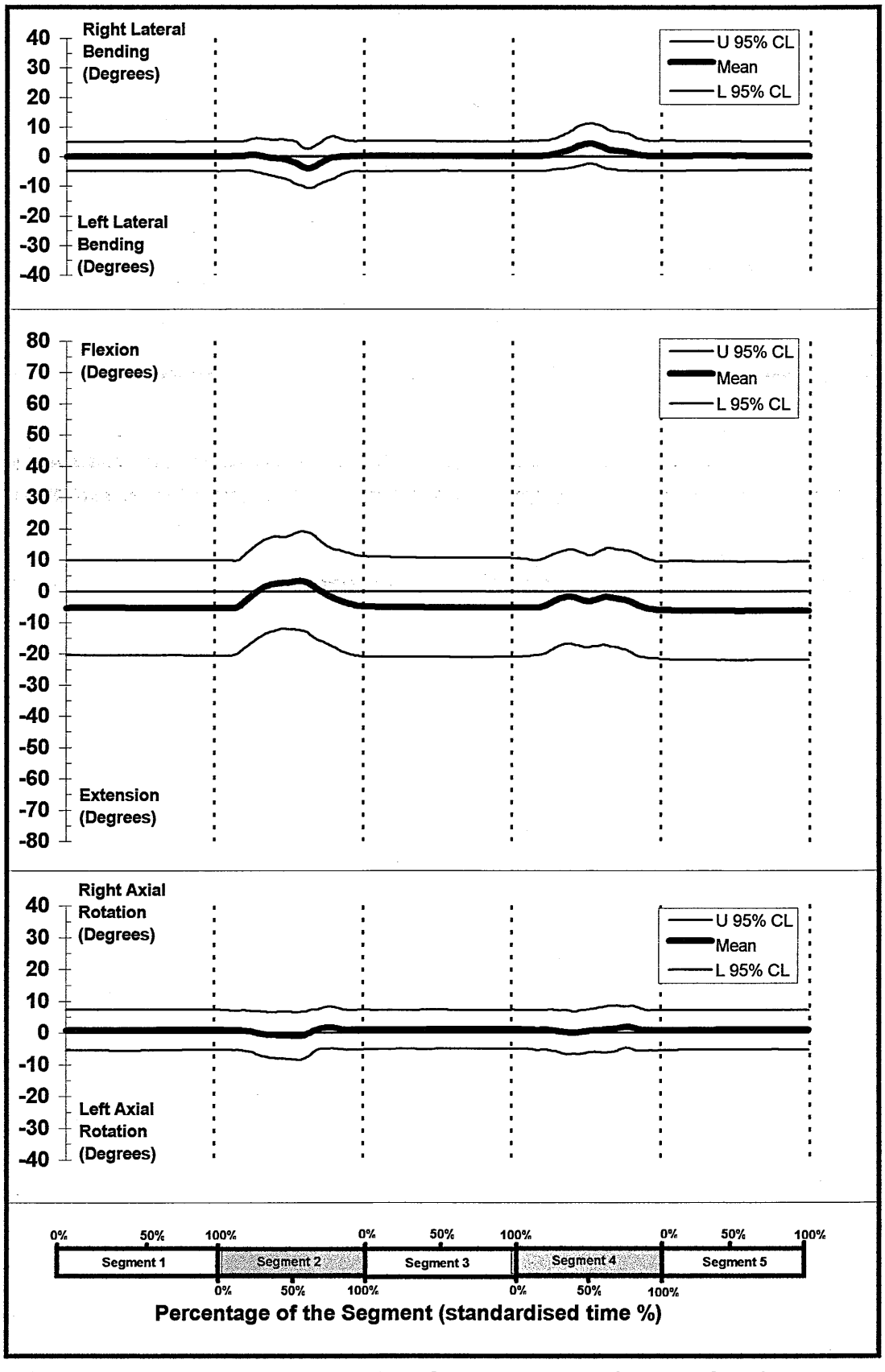


Figure 10.28 Interpolated mean plot of 100 healthy subjects performing the functional movement of going up and down a step

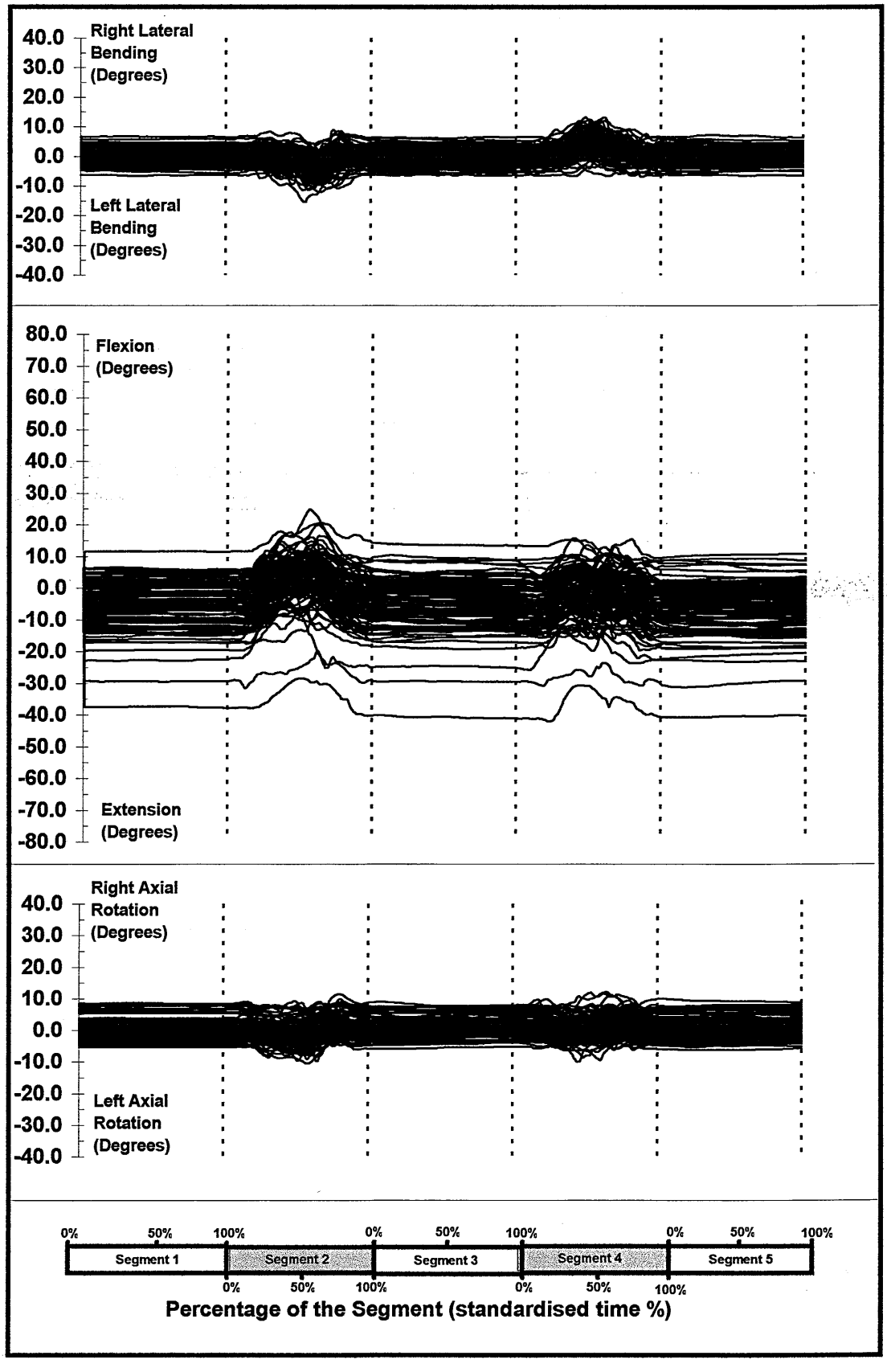


Figure 10.29 Interpolated individual plots of 100 healthy subjects performing the functional movement of going up and down a step

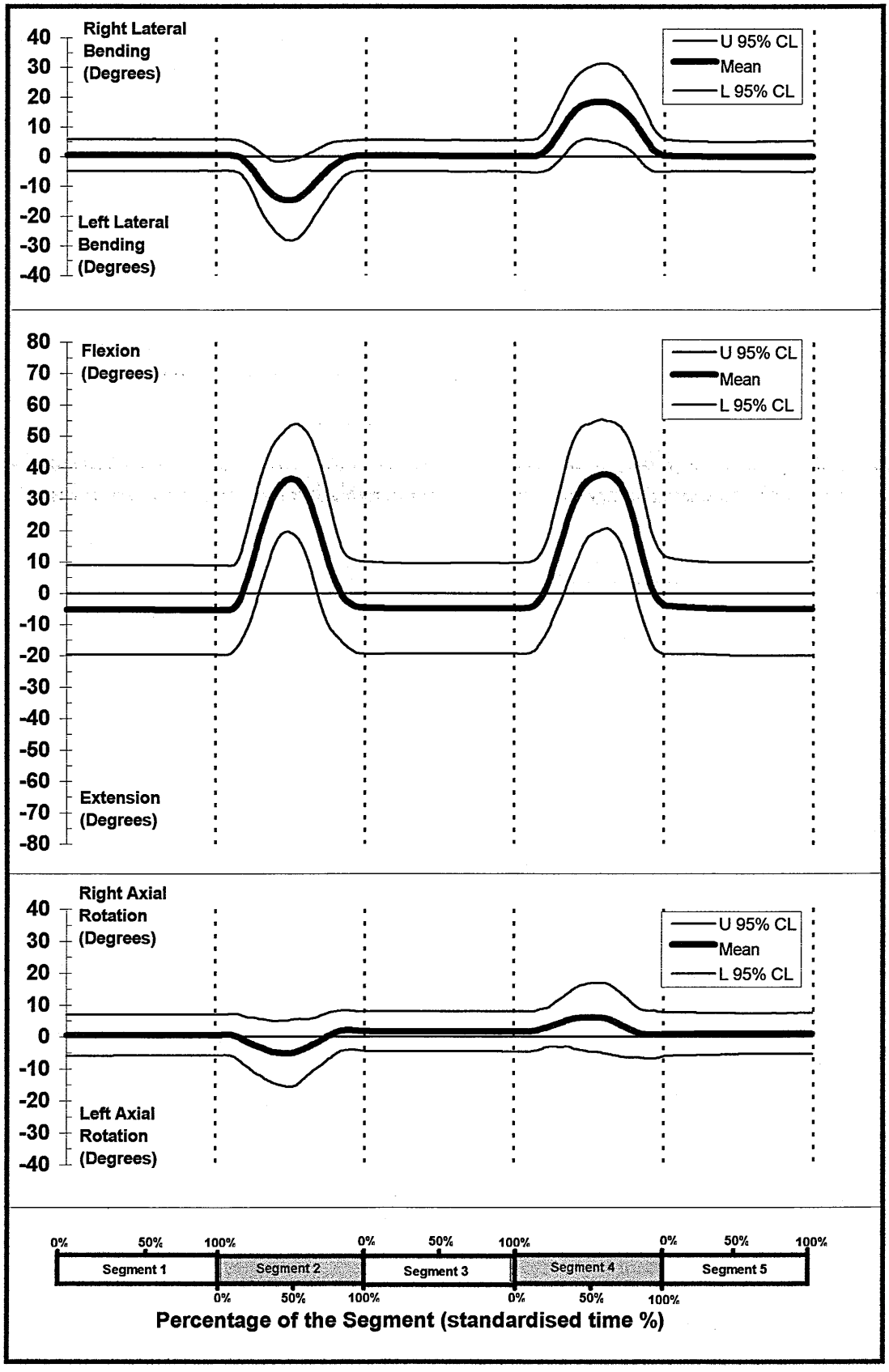


Figure 10.30 Interpolated mean plot of 100 healthy subjects performing the functional movement of picking up a box at the left side and putting it down at the right

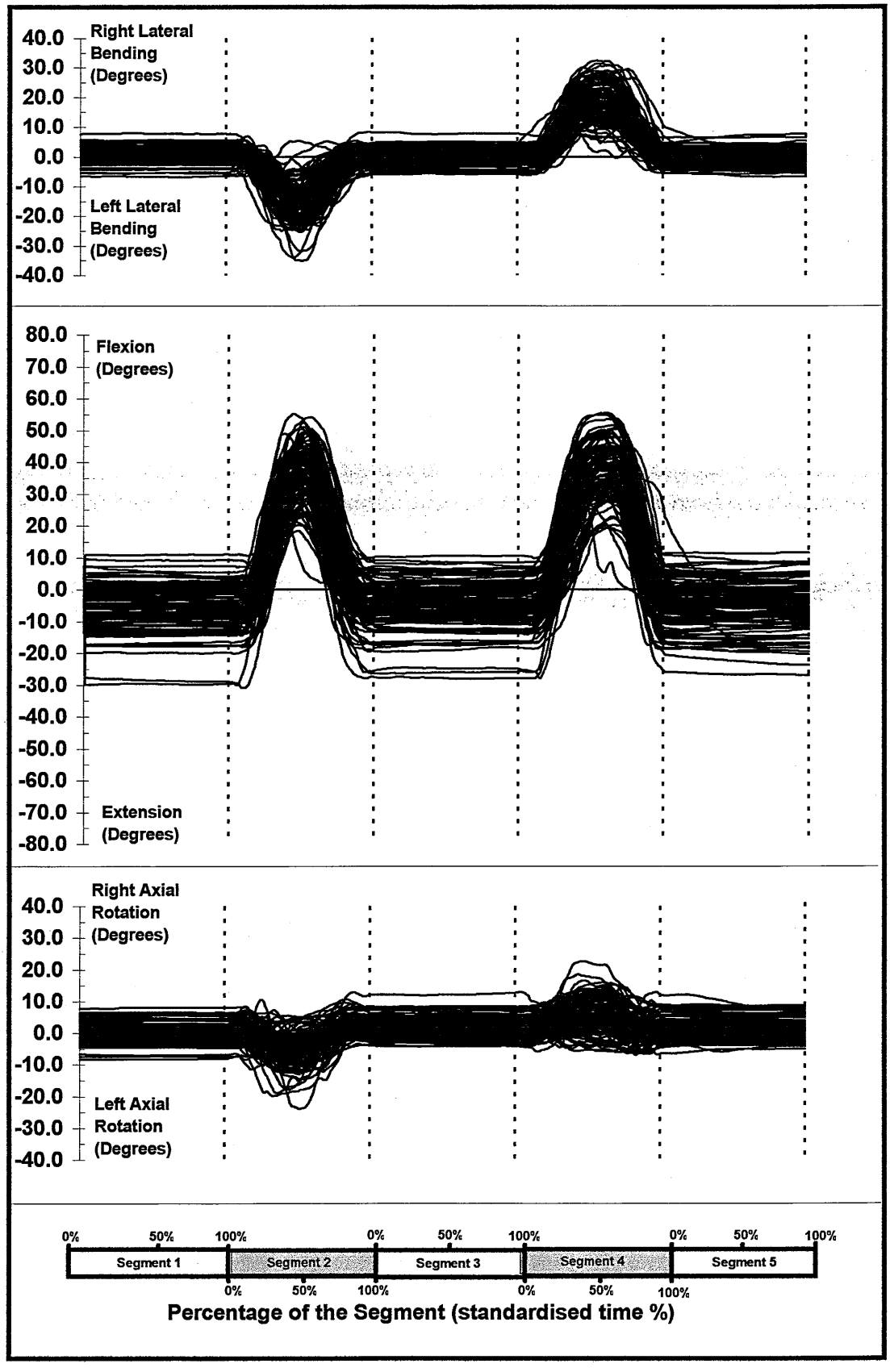


Figure 10.31 Interpolated individual plots of 100 healthy subjects performing the functional movement of picking up a box at the left side and putting it down at the right side.

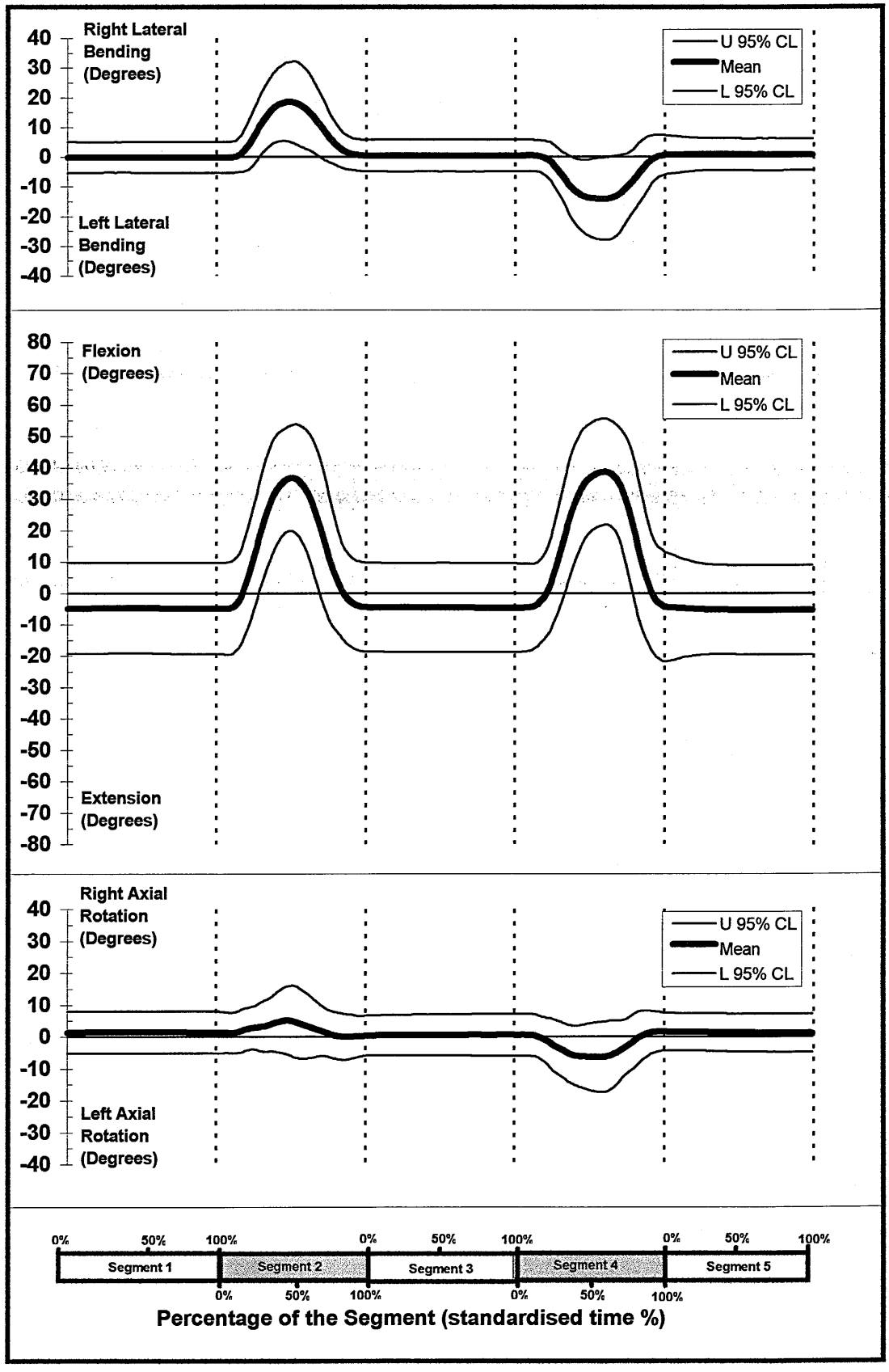


Figure 10.32 Interpolated mean plot of 100 healthy subjects performing the functional movement of picking up a box at the right and putting it down at the left.

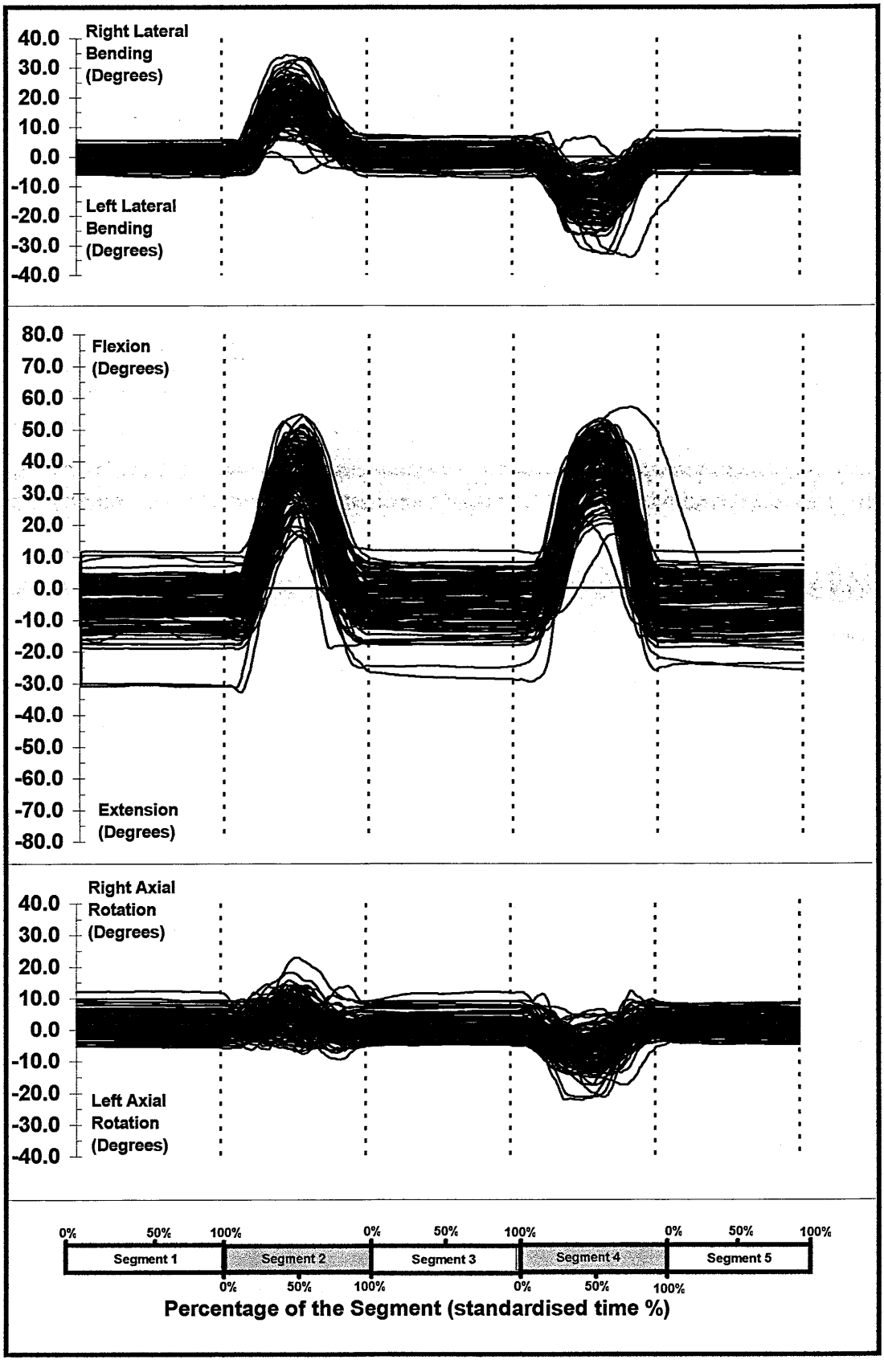


Figure 10.33 Interpolated individual plots of 100 healthy subjects performing the functional movement of picking up a box at the right and putting it down at the left.

10.3.2 Lumbar mobility excursion values of 4 functional movements in 100 healthy subjects.

An overview of the 3 dimensional excursions values for the 4 functional movements (sitting down and standing up from a stool, going up and down a step, picking up a box at the left de and putting it down at the right and picking up a box at the right and putting it down at the left) is provided in Tables 10.21 -10.25.

Standing from sitting and sitting from standing	Lateral Bending (Degrees)	Flexion-Extension (Degrees)	Axial Rotation (Degrees)
Mean	5.9	32.9	4.9
Standard Deviation	2.4	10.9	2.0
Upper 95% Confidence Level	10.6	54.2	8.8
Lower 95% Confidence Level	1.3	11.6	0.9
Maximum Value in Group	14.7	65.1	14.3
Minimum Value in Group	2.2	12.1	1.9
Median	5.4	31.5	4.5
97.5th percentile	11.8	52.7	9.8
2.5th Percentile	2.7	13.3	2.1

Table 10.21 3 Dimensional kinematic pattern excursion values for the functional activity of sitting down on a stool and standing up

Going up and down a step	Lateral Bending (Degrees)	Flexion-Extension (Degrees)	Axial Rotation (Degrees)
Mean	11.3	13.9	6.7
Standard Deviation	4.1	4.7	2.7
Upper 95% Confidence Level	19.3	23.0	12.0
Lower 95% Confidence Level	3.4	4.8	1.4
Maximum Value in Group	21.5	30.4	12.9
Minimum Value in Group	3.8	6.5	1.7
Median	11.1	13.3	6.2
97.5th percentile	20.1	24.8	12.3
2.5th Percentile	4.7	6.9	2.6

Table 10.22 3 Dimensional kinematic pattern excursion values for the functional activity of going up a step and stepping down.

Picking up a box at the left side	Lateral Bending (Degrees)	Flexion-Extension (Degrees)	Axial Rotation (Degrees)
Mean	35.0	47.3	15.2
Standard Deviation	10.6	8.2	6.5
Upper 95% Confidence Level	55.8	63.5	27.8
Lower 95% Confidence Level	14.2	31.1	2.6
Maximum Value in Group	62.8	72.7	37.6
Minimum Value in Group	15.0	32.0	3.9
Median	33.7	47.6	14.2
97.5th percentile	53.8	63.5	30.9
2.5th Percentile	17.6	33..6	6.8

Table 10.23 3 Dimensional kinematic pattern excursion values for the functional activity of picking up a box at the left side and putting it down at the right side.

Picking up a box at the right side	Lateral Bending (Degrees)	Flexion-Extension (Degrees)	Axial Rotation (Degrees)
Mean	34.5	47.4	15.5
Standard Deviation	11.1	8.7	6.8
Upper 95% Confidence Level	56.2	64.6	28.9
Lower 95% Confidence Level	12.7	30.3	2.1
Maximum Value in Group	62.1	76.9	36.9
Minimum Value in Group	12.8	27.8	5.3
Median	34.1	47.4	13.9
97.5th percentile	54.6	62.7	31.5
2.5th Percentile	16.1	30.2	6.4

Table 10.24 3 Dimensional kinematic pattern excursion values value for the functional activity of picking up a box at the right side and putting it down at the left side.

Table 10.25 gives a summary of the kinematic patterns displayed by 100 healthy subjects during gross movements in standing.

Functional Activity	Primary Movement	Main Excursion Values Primary Movement	Coupled Movements	Main Excursion Values Coupled Movement
Sit to Stand	Flexion	32.9 (10.9)	Lateral Bending Axial Rotation	5.9(2.4) 4.9(2.0)
Going up and down a step	Flexion	13.9 (10.9)	Lateral Bending Axial Rotation	11.3 (4.1) 6.7 (2.7)
Picking up a box at the left side and putting it down at the right	Flexion	47.3 (8.2)	Lateral Bending Axial Rotation	35.0 (10.6) 15.2 (6.5)
Picking up a box at the left side and putting it down at the right	Flexion	47.3 (8.7)	Lateral Bending Axial Rotation	34.5 (11.1) 15.5 (6.8)

Table 10.25 Summary of primary and coupled movements in 100 healthy subjects

A distinct quantifiable movement pattern emerged during the functional movements of rising to stand from sitting and sitting down from standing, going up a step of 20 cm with the left leg first and picking up a box on the left side and putting it down on the right side and the reverse of this.

The primary movement of flexion during sit to stand and stand to sit was coupled with little lateral bending and axial rotation. No particular trend emerged as to which side of lateral bending and axial rotation was dominant.

During going up and down a step the primary movement of flexion was coupled with left lateral bending during the up phase and to the right during the going down phase. Very small changes were noticed in axial rotation.

During the activity of picking up a box at the left side and putting it down at the right again a clear pattern emerged. Forward flexion (47.2) was coupled with lateral bending (35.0) and to a lesser extent to axial rotation (15.2). Nearly identical mean excursion values were obtained when the subjects performed this movement in the opposite direction.

11. Results: Comparison of kinematics in low back pain patients and healthy subjects.

11.1 Analysis of Gross Movements in 41 low back pain patients

11.1.1 Lumbar mobility excursion plots in low back pain patients (gross movements)

Figures 11.1 to 11.12 display the interpolated plots of the 41 low back pain patients, during their first measurement, performing the gross movements of forward flexion, extension, lateral bending and axial rotation in standing.

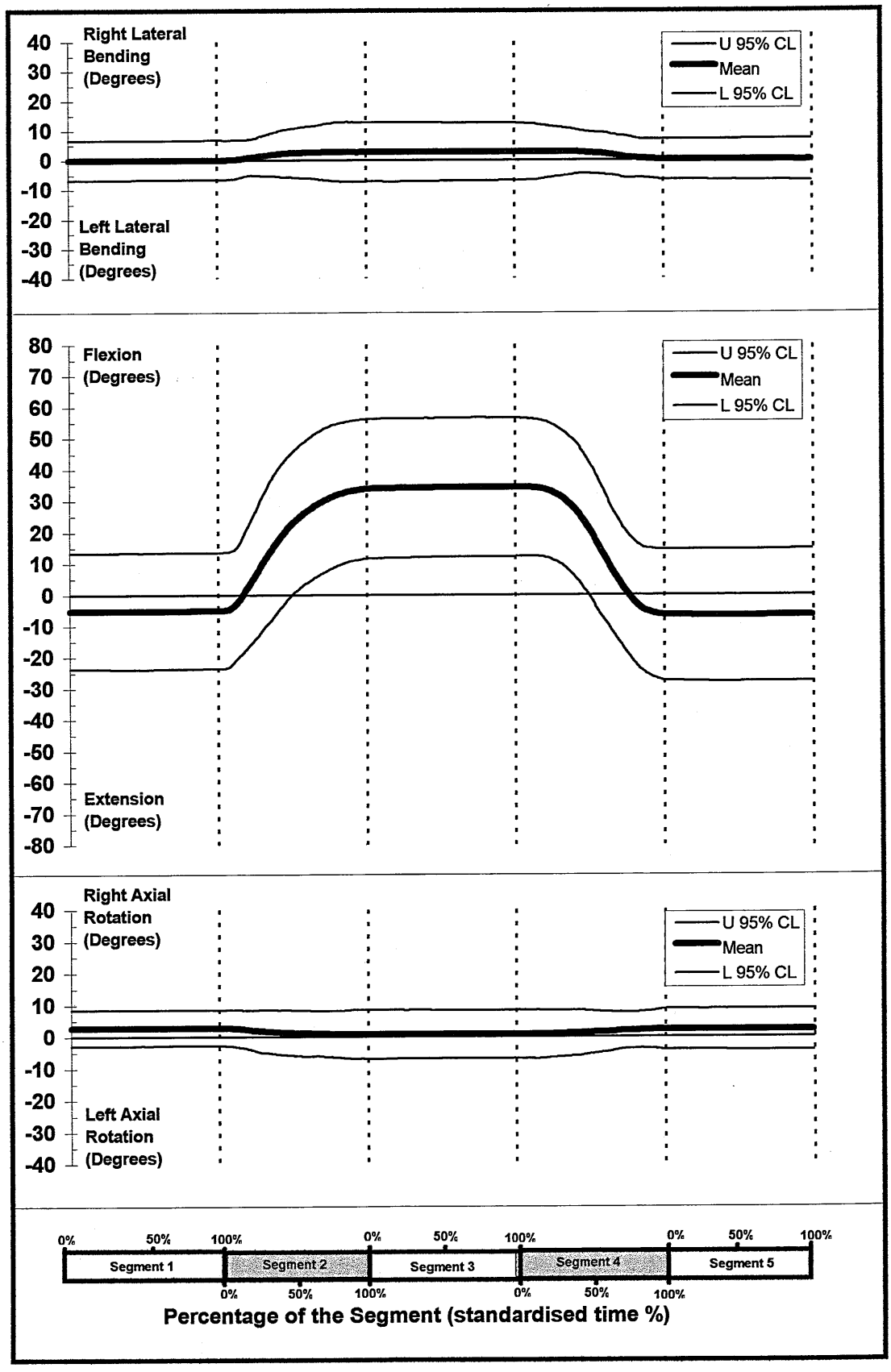


Figure 11.1 Interpolated mean plot of 41 patients performing forward flexion in standing

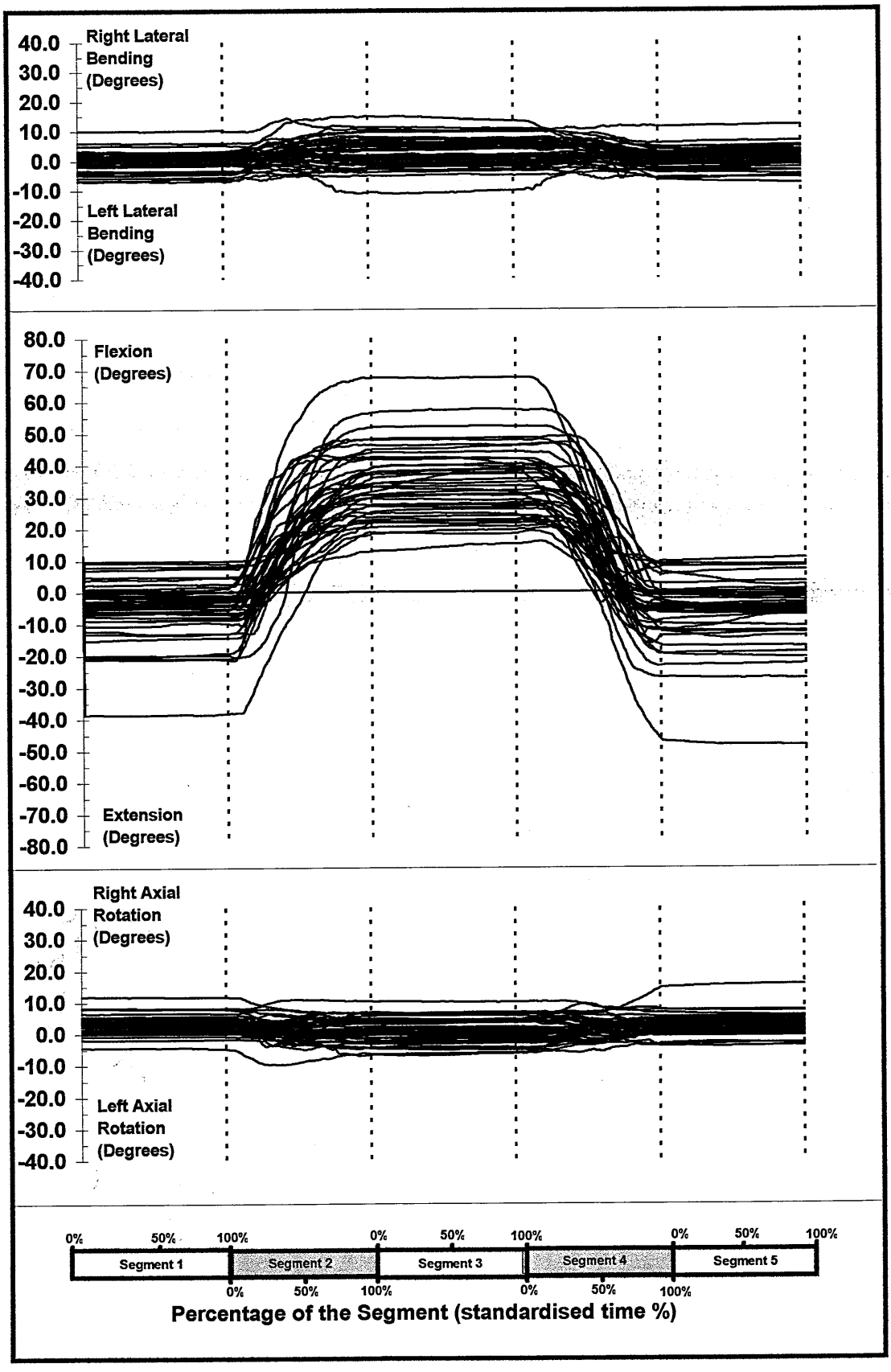


Figure 11.2 Interpolated individual plots of 41 patients performing forward flexion in standing

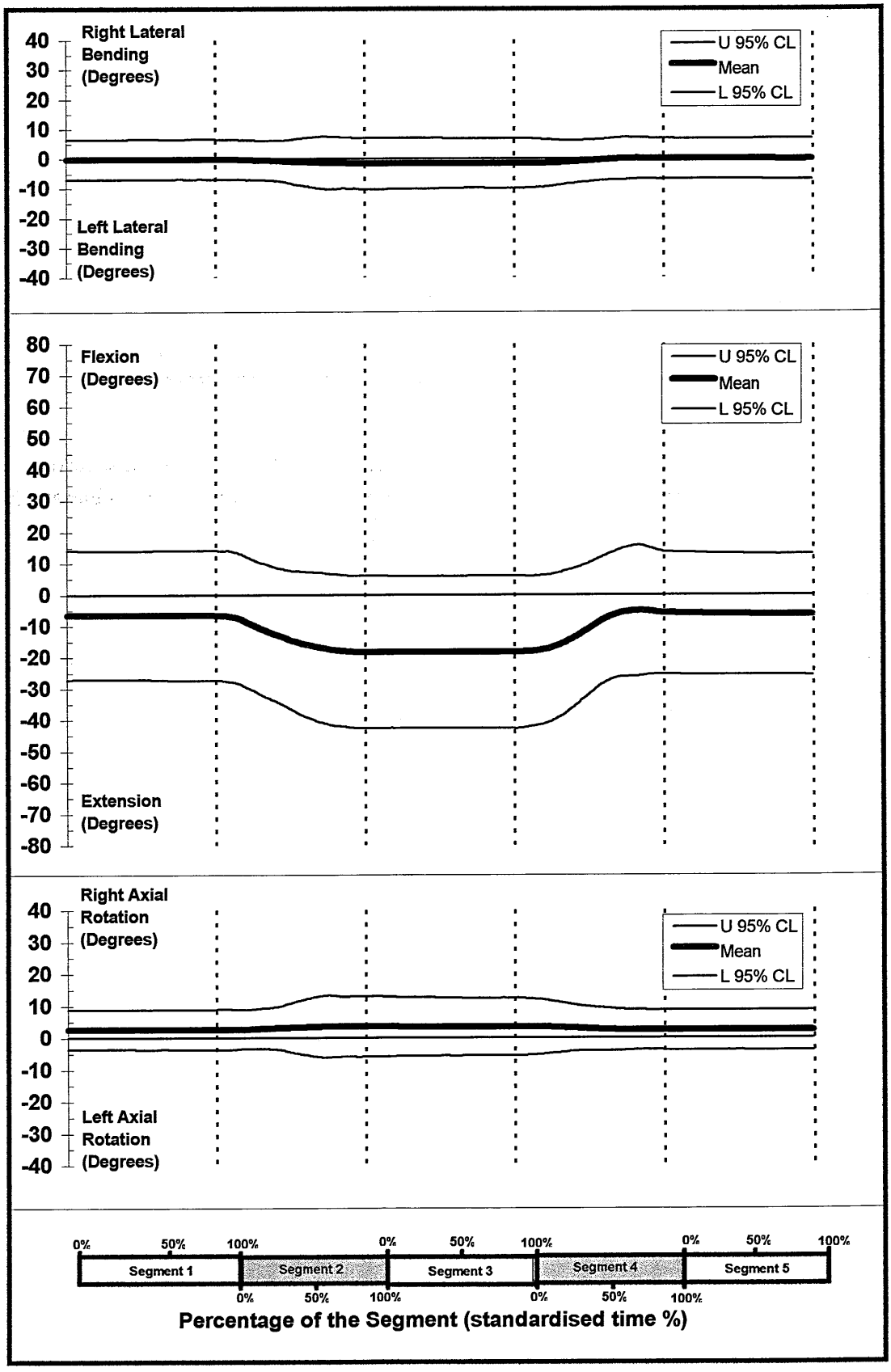


Figure 11.3 Interpolated mean plot of 41 patients performing extension in standing

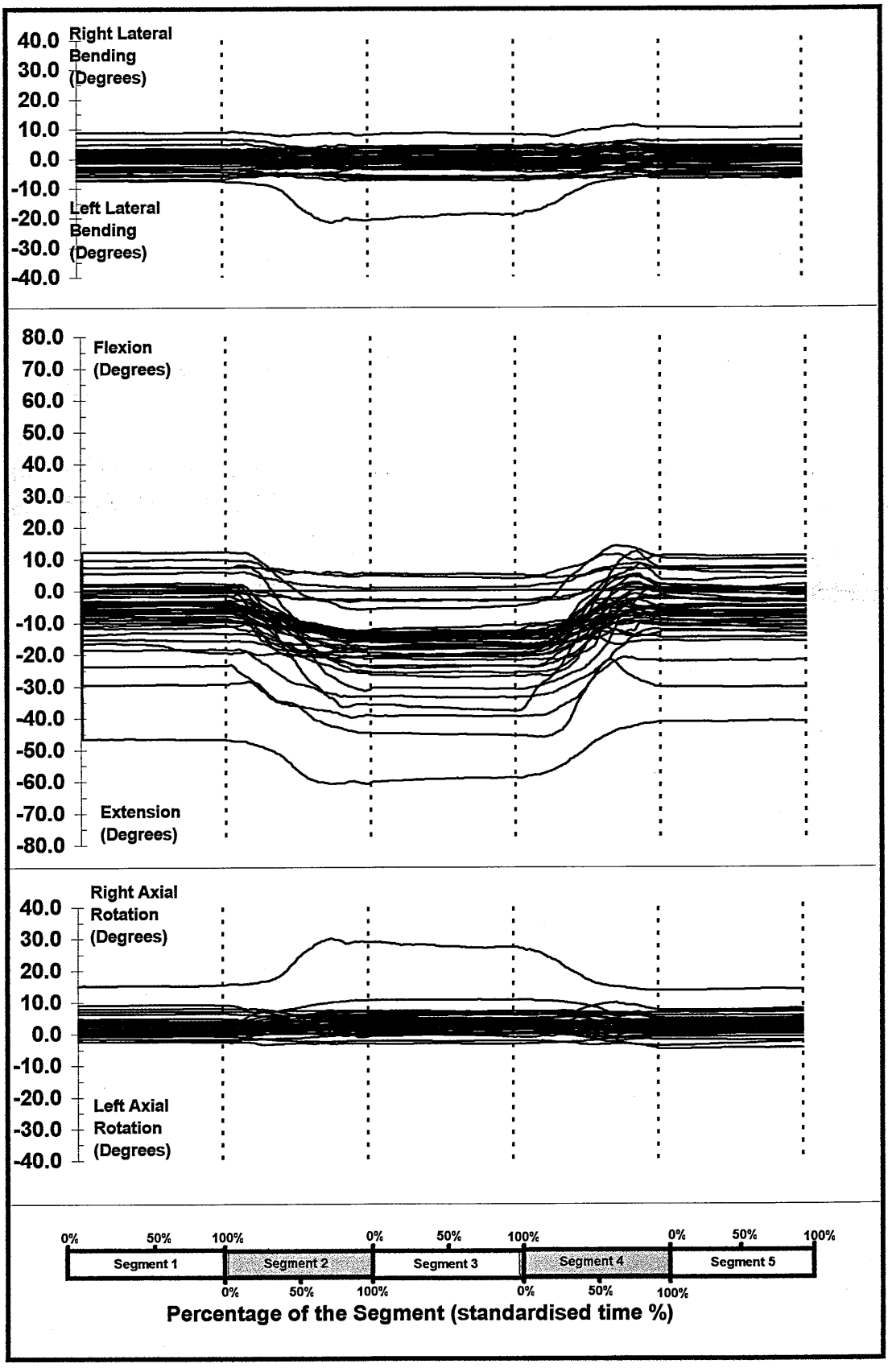


Figure 11.4 Interpolated individual plots of 41 patients performing extension in standing

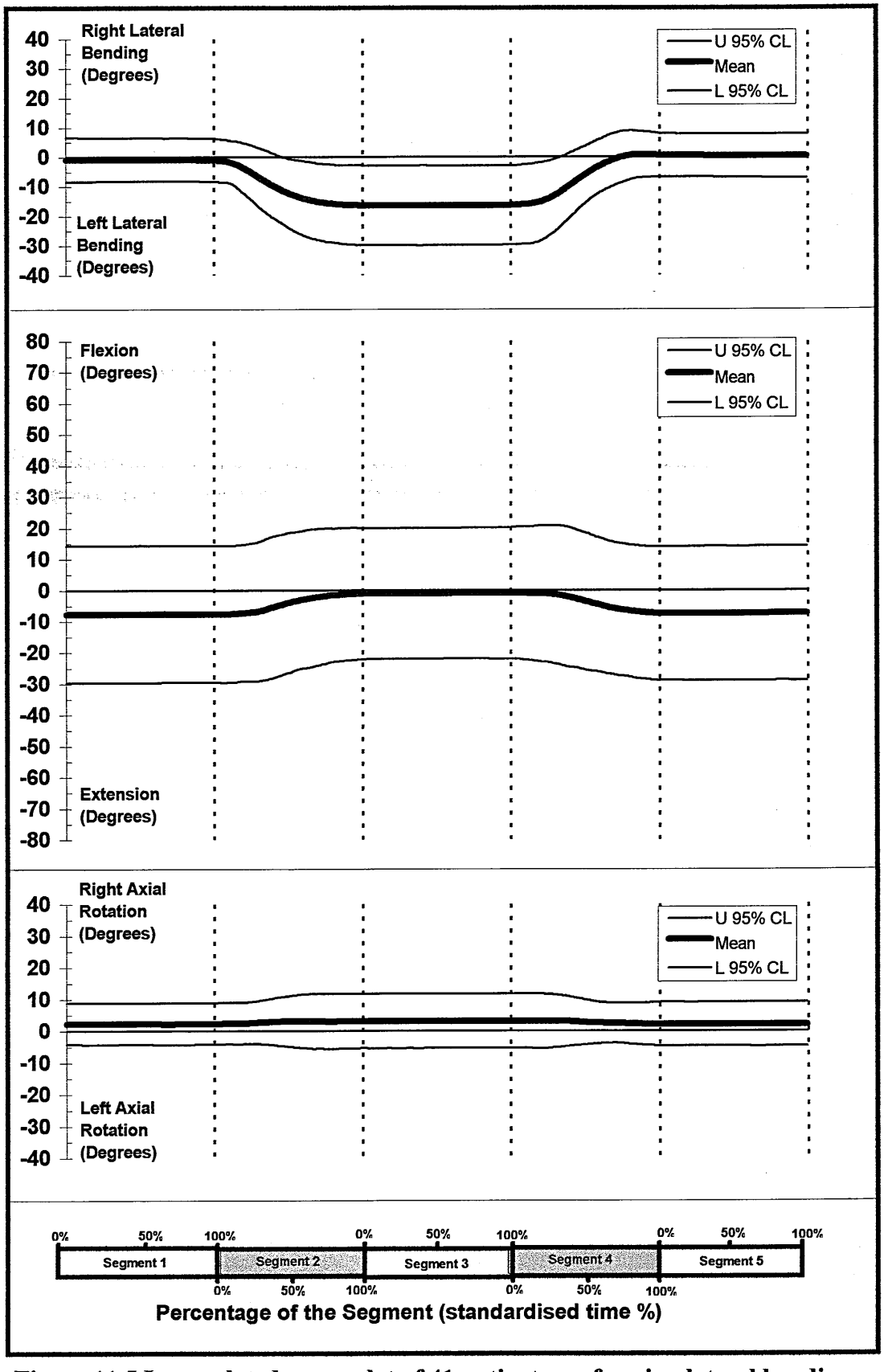


Figure 11.5 Interpolated mean plot of 41 patients performing lateral bending to the left in standing

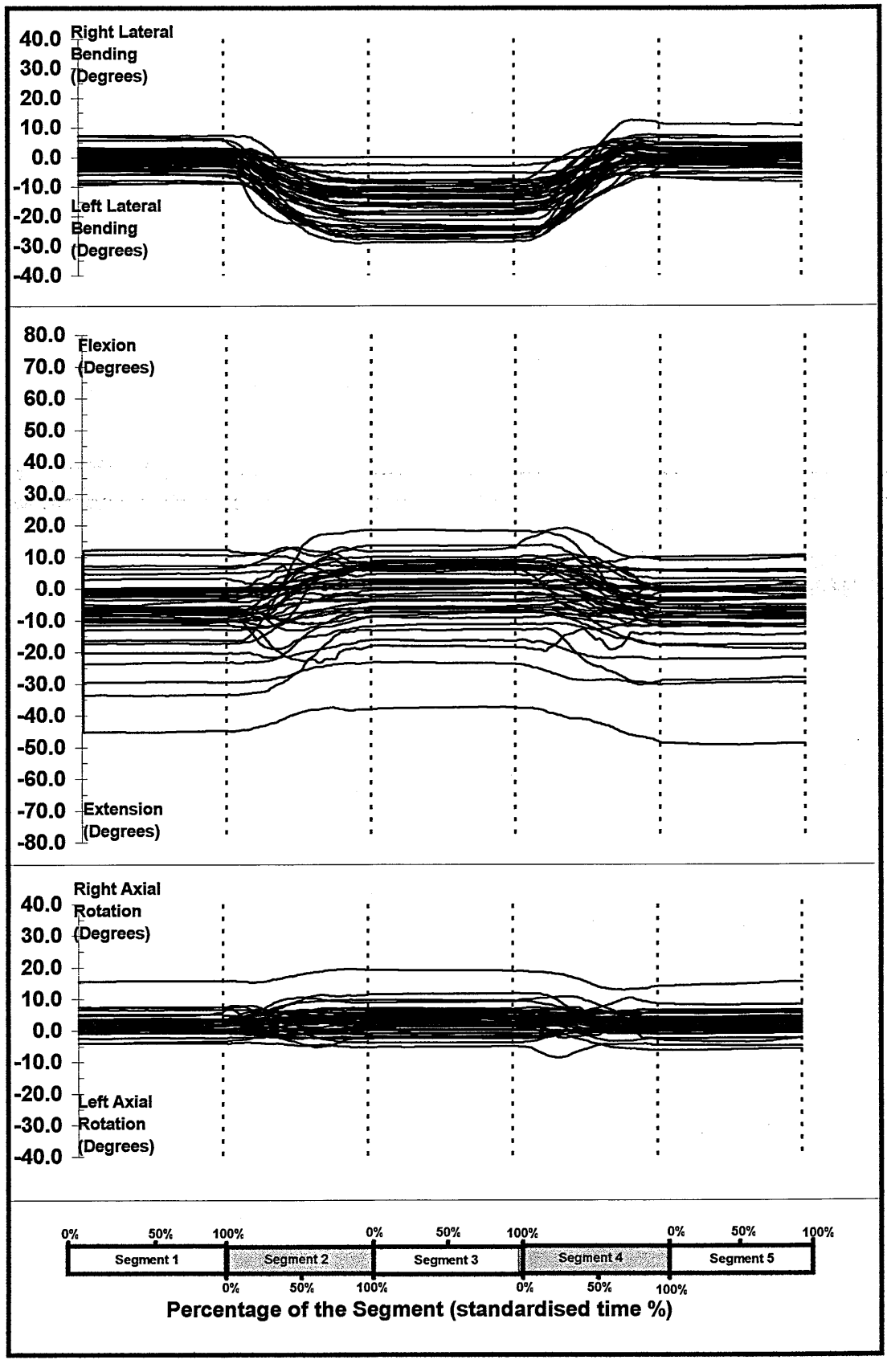


Figure 11.6 Interpolated individual plots of 41 patients performing lateral bending to the left in standing

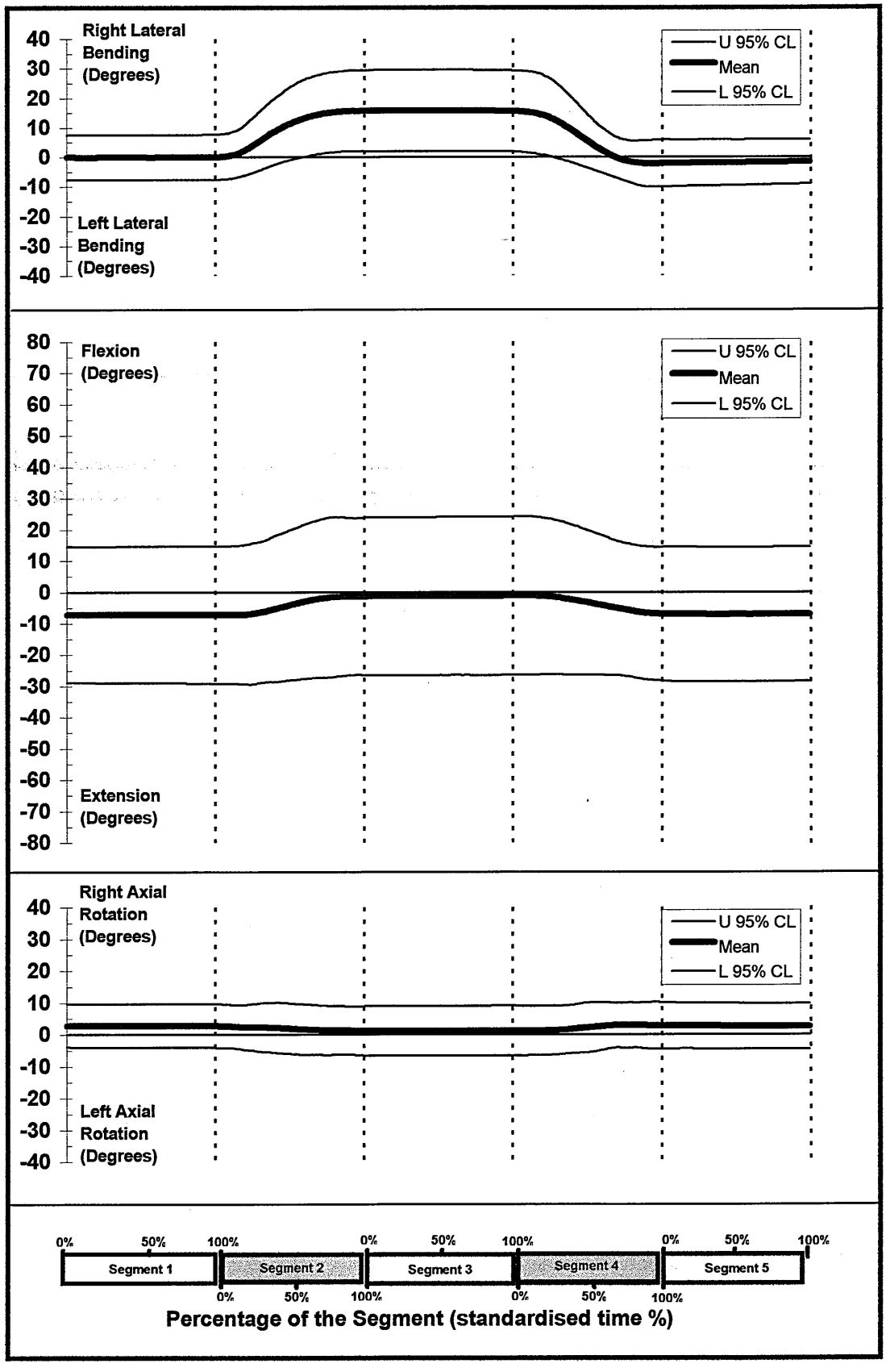


Figure 11.7 Interpolated mean plot of 41 patients performing lateral bending to the right in standing

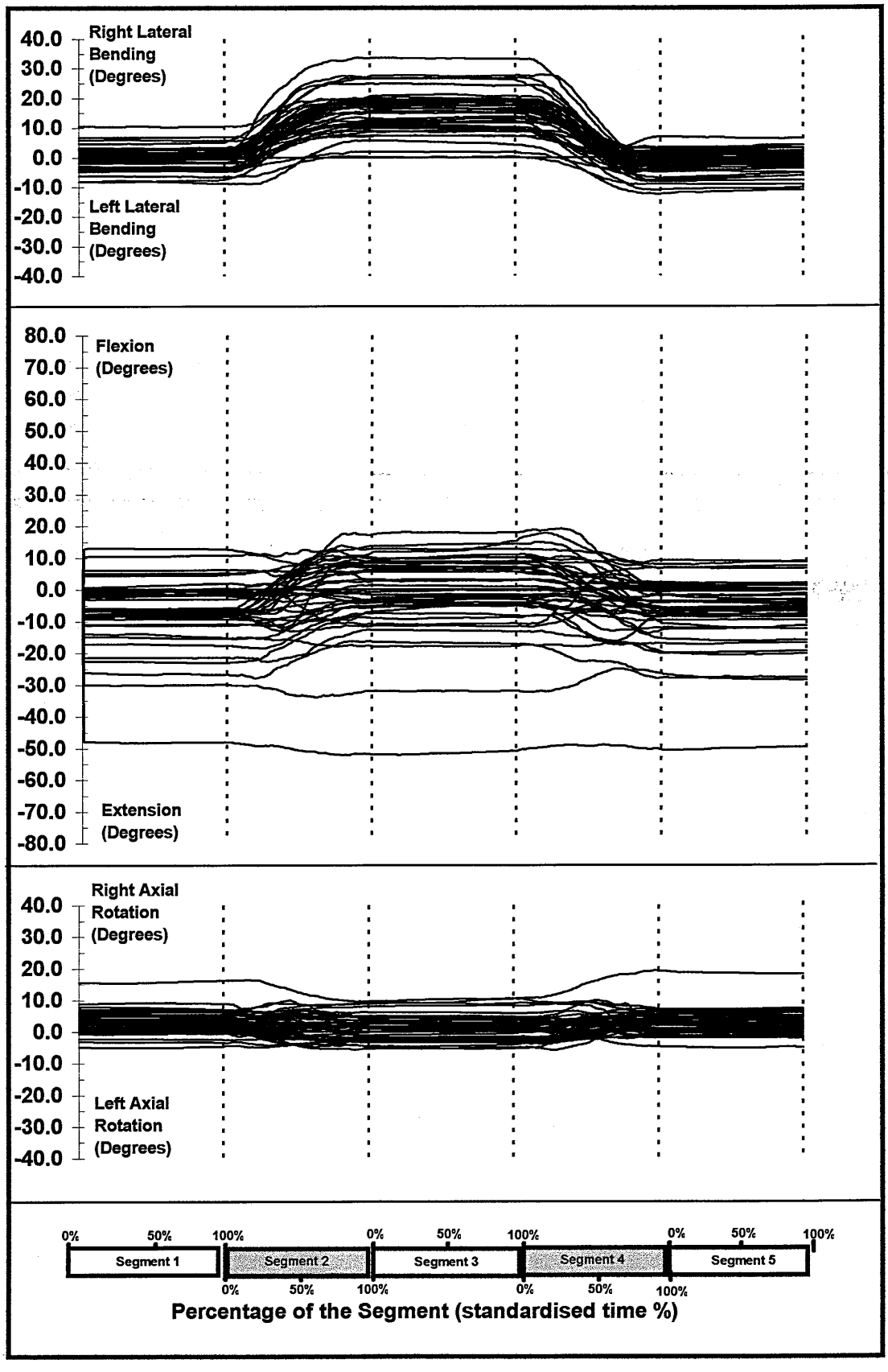


Figure 11.8 Interpolated individual plots of 41 patients performing lateral bending to the right in standing

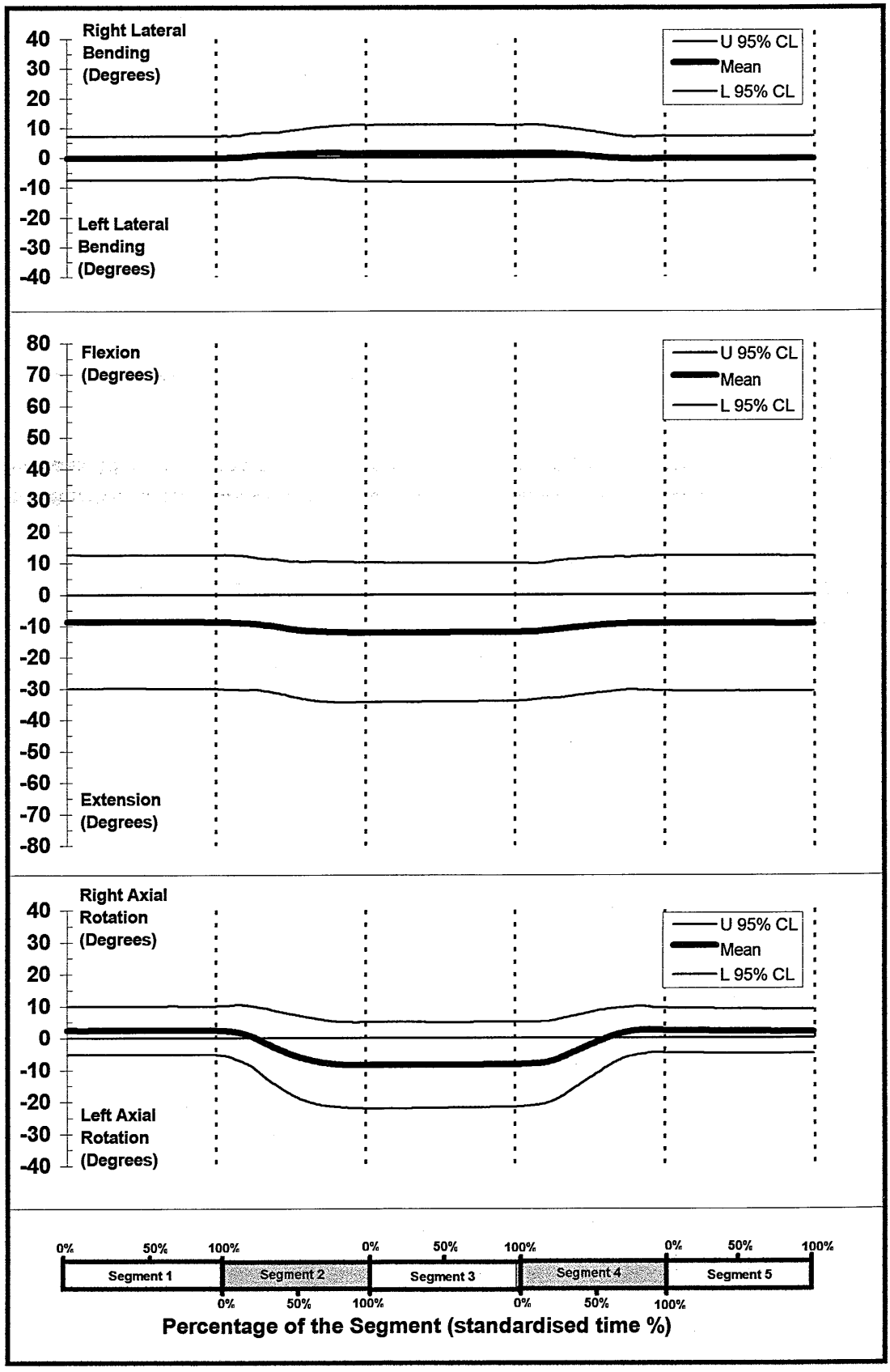


Figure 11.9 Interpolated mean plot of 41 patients performing axial rotation to the left in standing

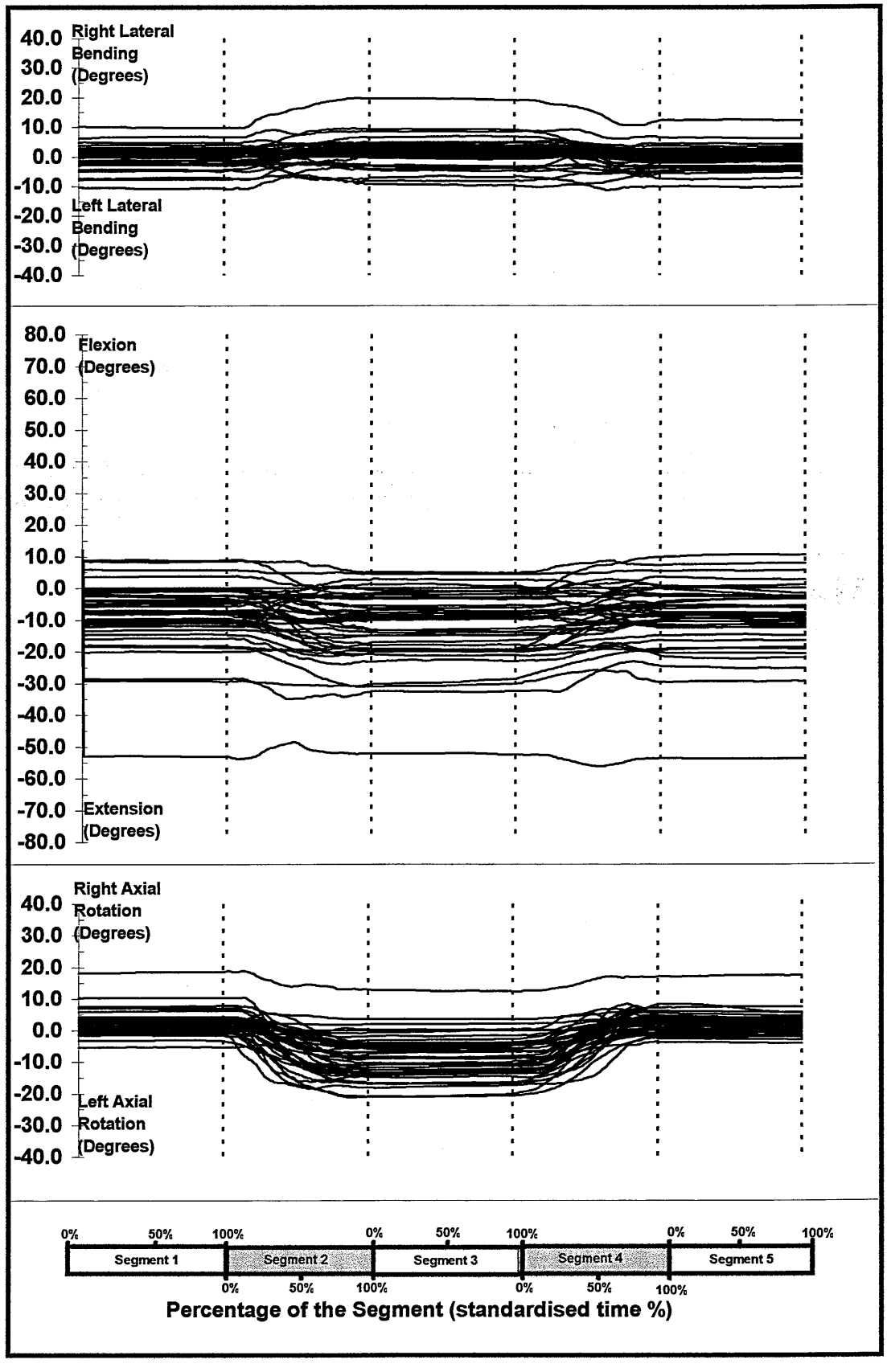


Figure 11.10 Interpolated individual plots of 41 patients performing axial rotation to the left in standing

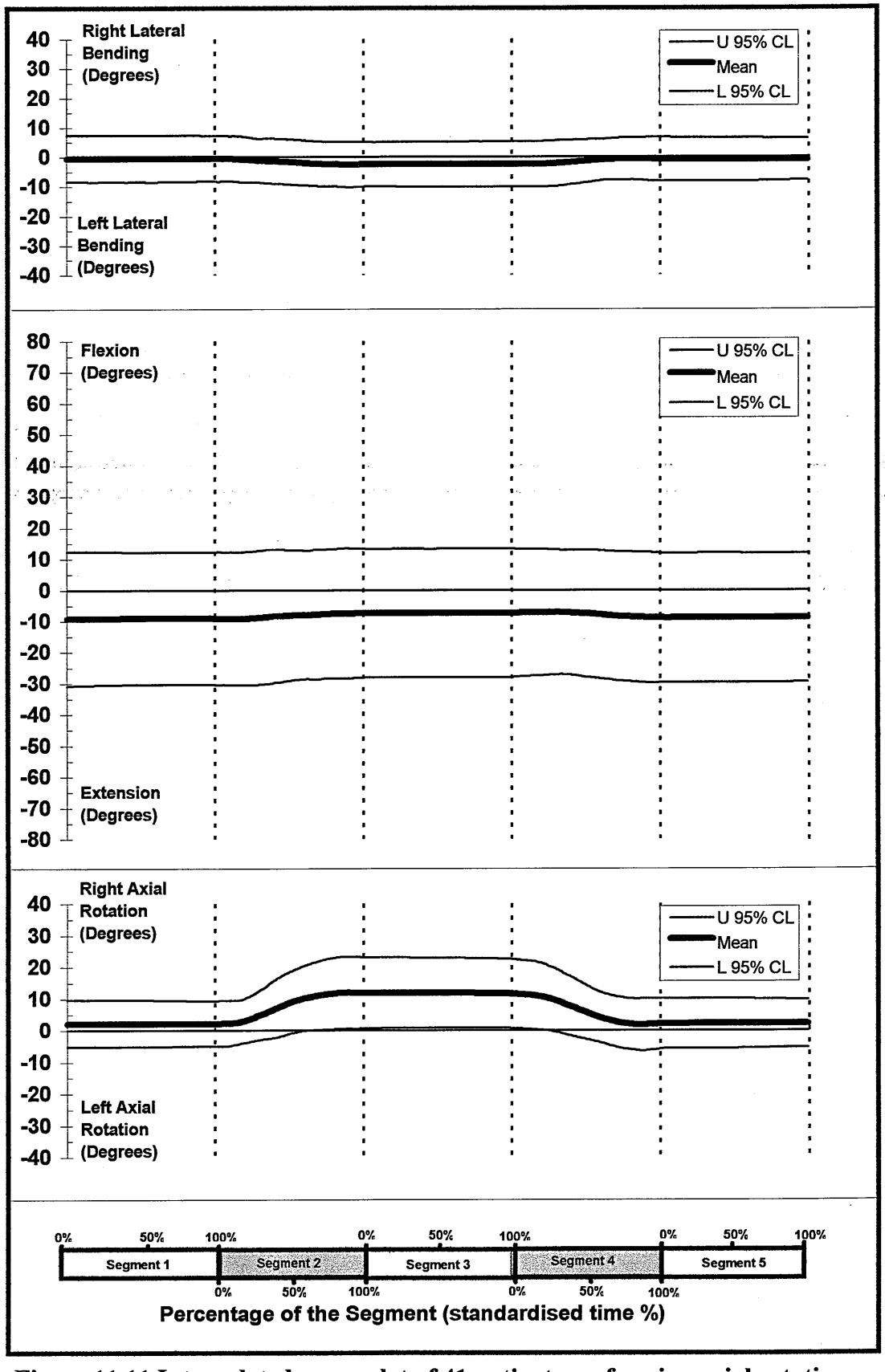


Figure 11.11 Interpolated mean plot of 41 patients performing axial rotation to the right in standing

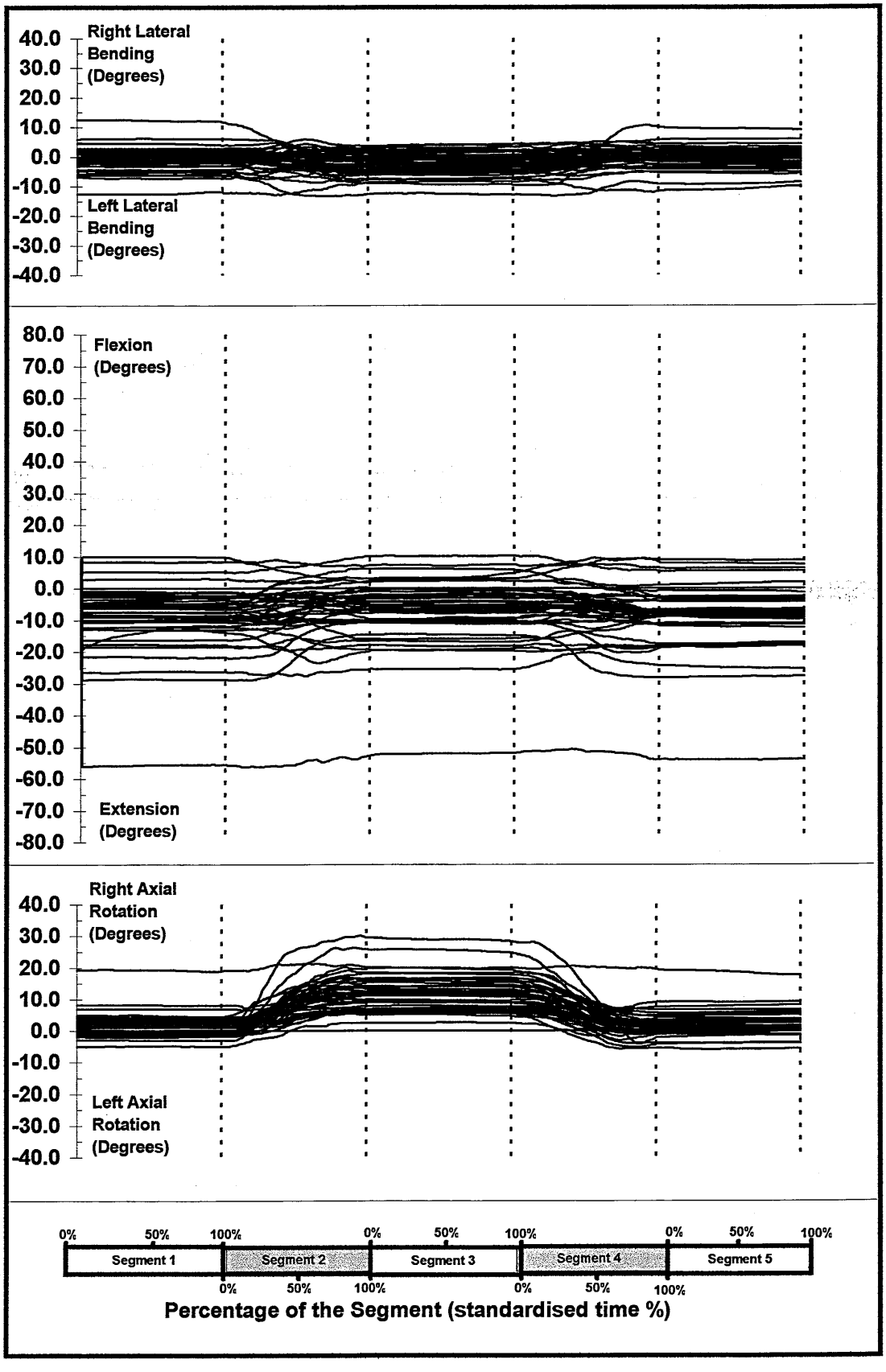


Figure 11.12 Interpolated individual plots of 41 patients performing axial rotation to the right in standing

11.1.2 Lumbar mobility excursion values in low back pain patients (gross movements)

An overview of the excursion values for coupled movements during 6 gross movements in 41 low back pain patients and prior to a mobilisation is provided in table 11.1

Gross Movement	Coupled Movement	Value (Degrees)
Flexion	Lat. Bend	5.6
	Axial Rotat.	4.6
Extension	Lat. Bend	3.0
	Axial Rotat.	3.5
LBL	Flex.-Ext.	10.2
	Axial Rotat.	5
LBR	Flex.-Ext.	10.3
	Axial Rotat.	5.0
ARL	Lat. Bend.	4.3
	Flex-Ext.	6.6
ARR	Lat. Bend.	4.9
	Flex-Ext.	6.1

Table 11.1 Mean excursion values of coupled movements for 41 patients prior to mobilisation performing 6 gross movements.

An overview of the excursion values for the primary movement, recorded in 41 low back pain patients prior to a mobilisation treatment is provided in table 11.2.

	Flexion	Extension	Lateral Bending Left	Lateral Bending Right	Axial Rotation Left	Axial Rotation Right
Mean	43.7	15.7	18.2	19.0	12.4	11.4
SD	13.7	9.2	6.6	7.3	5.9	5.5
Upper 95% CL	70.0	33.8	31.2	33.2	24.0	22.1
Lower 95% CL	16.2	-2.4	5.2	4.7	0.8	0.6
Maximum in Group	78.7	46.0	34.1	37.1	29.7	28.6
Minimum in Group	15.6	3.7	4.1	6.1	1.8	2.4
Median	43.2	14.5	17.3	18.2	10.2	10.7
97.5th percentile	73.0	39.6	29.2	32.1	24.0	23.2
2.5th percentile	16.1	4.2	5.8	6.9	4.1	3.8

Table 11.2 Mean excursion values (in degrees) for 41 patients included in the randomised controlled trial and prior to mobilisation performing 6 gross movements (primary movements)

The values in table 11.2 indicate similar relative magnitudes between the six values as those reported for the healthy subjects. In other words, flexion gives the highest value, extension approximately half of the value in flexion, lateral rotation approximately the same value as extension and axial rotation approaching 60% of extension and lateral rotation value.

11.1.3 Analysis of differences in excursion values between low back patients and healthy subjects (gross movements)

The excursion values for the 6 gross movements, obtained by the healthy subject sample (n=100) were compared with the excursion values obtained by LBP-patients (n=41).

Gross Movement	Primary Movement	Value Patients	Value Healthy Subjects	Coupled Movements	Value Patients	Value Healthy Subjects
Flexion	Flexion	43.1	55.4	Lat. Bend Axial Rotat.	5.6 4.6	5.5 5.9
Extension	Extension	15.7	23.2	Lat. Bend Axial Rotat.	3.0 3.5	3.0 3.6
LBL	LBL	18.2	21.7	Flex.-Ext. Axial Rotat.	10.2 5	12.1 4.7
LBR	LBR	19.0	22.9	Flex.-Ext. Axial Rotat.	10.3 5.0	11.8 5.0
ARL	ARL	12.4	14.0	Lat. Bend. Flex-Ext.	4.3 6.6	5.0 7.9
ARR	ARR	11.4	13.5	Lat. Bend. Flex-Ext.	4.9 6.1	4.7 6.7

Table 11.3 Comparison of Excursion mobility between patients and healthy subjects-groups (primary and coupled movements)

11.1.4 Statistical analysis of differences between LBP-patients and healthy subjects (gross movements)

It is apparent from table 11.3 that no substantial differences were recorded in the coupled movements between the patients and the healthy subjects in none of the 6 gross movements (maximum difference:-1.9 degrees, mean difference: 0.5 degrees). However, when analysing the primary movement, a substantial difference could be observed. Consequently, a statistical analysis of the differences in excursion values for the primary movements was performed.

The null hypothesis of no difference between the LBP-patient-group and the healthy subjects-group was tested using a t-test for independent samples (2-tailed). The results of this analysis are displayed in Table 11.4.

Significant differences (α-level = 0.0083, Bonferroni correction) in excursions between low back pain patients and healthy subjects were found for the gross movements of flexion, extension and lateral bending to the left and right. No significant differences (α = 0.0083) were found for axial rotation to the left and right.

Movement	Mean Patients (Degrees)	Mean Healthy Subjects (Degrees)	Levene's Test for Equality of Variances p-values	Equal Variance assumed	t-test for independent samples*	Mean Difference (Degrees)	Significant difference	95% Confidence Interval of the Mean (Degrees)	
Flexion	43.0	55.4	0.02	No	$p<0.001^{+}$	12.3	Yes	-17.02	-7.69
Extension	15.6	23.1	0.21	Yes	$p<0.001^{+}$	7.4	Yes	-11.13	-3.82
Lateral Bend left	18.1	21.7	0.90	Yes	$p<0.001^{+}$	3.5	Yes	-5.89	-1.15
Lateral Bend Right	18.9	22.8	0.48	Yes	$p<0.001^{+}$	3.8	Yes	-6.37	-1.37
Axial Rotation Left	12.4	14.0	0.33	Yes	p= 0.114	1.6	No	-3.71	0.41
Axial Rotation Right	11.3	13.5	0.69	Yes	p= 0.036	2.1	No	-4.17	0.13

***t-test for independent samples (2-tailed)**

$^{+}$ Significant following Bonferroni Correction (α becomes 0.05÷6=0.0083)

Table 11.4 Statistical Analysis of the differences in excursion between patients and healthy subjects-groups (primary movements).

Summary: Differences between patients and healthy subjects in gross movements

- LBP-patients showed, in general, the same kinematic patterns as healthy subjects when performing gross movements. No differences in movement pattern could be observed from the plots produced.
- The patient group showed a significant ($\alpha = 0.0083$) decrease in primary movement excursion values in 4 out of 6 gross movements (table 11.4). Only for axial rotation was the difference not significant.
- No important differences in coupled movement excursion values were observed. Only small increases or decreases in value were noted (table 11.3).

11.2 Analysis of the functional movements in 41 low back pain patients

11.2.1 Lumbar mobility excursion plots in low back patients (functional movements)

The interpolated plots of the 41 Low back pain patients, performing the 4 functional movements (sitting down and standing up from a stool, going up and down a step, picking up a box at the left side and putting it down at the right and picking up a box at the right and putting it down at the left) are displayed in figures 11.13 to 11.20.

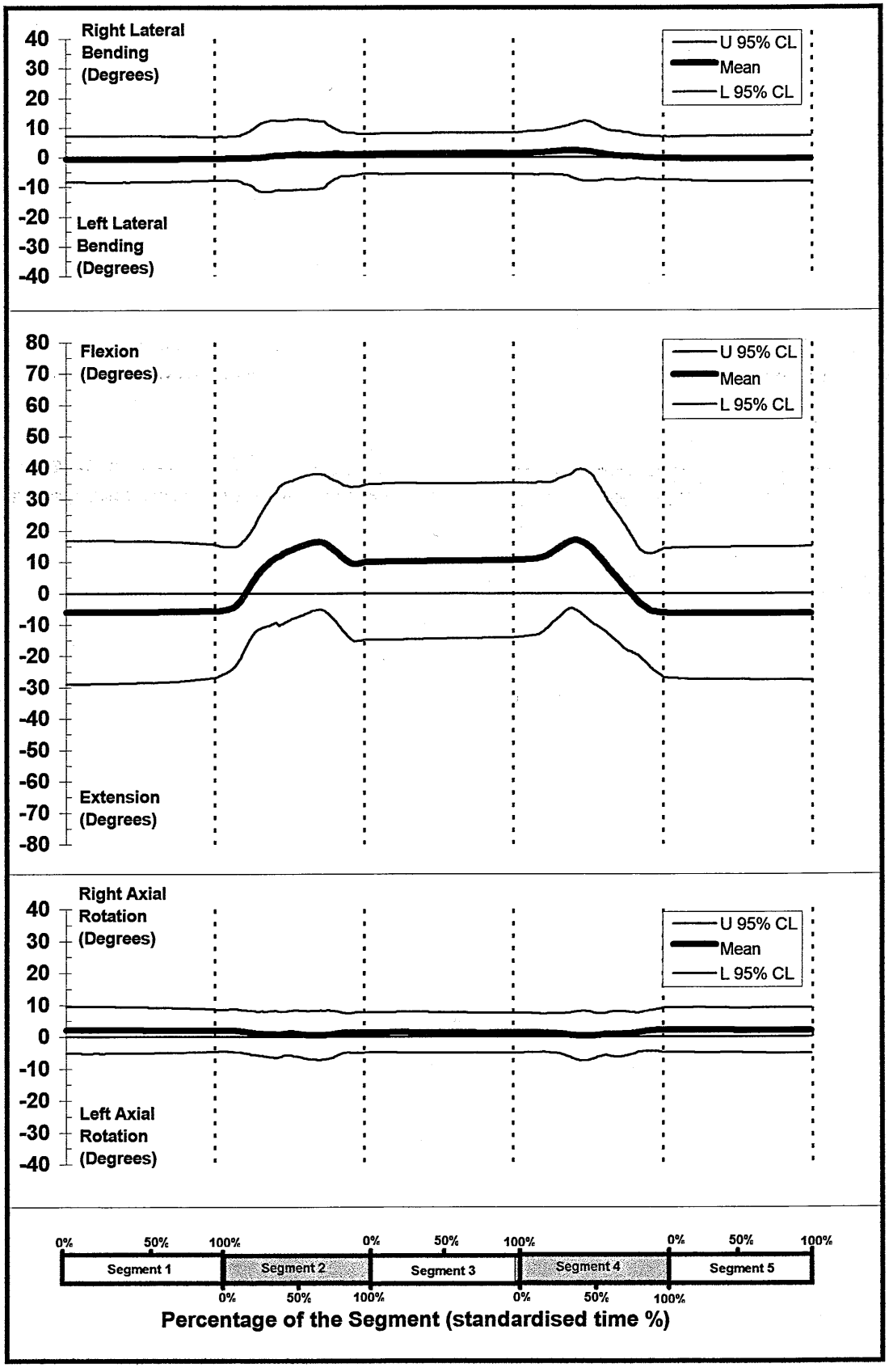


Figure 11.13 Interpolated mean plot of 41 patients performing the functional movement of sitting down and standing up from a stool.

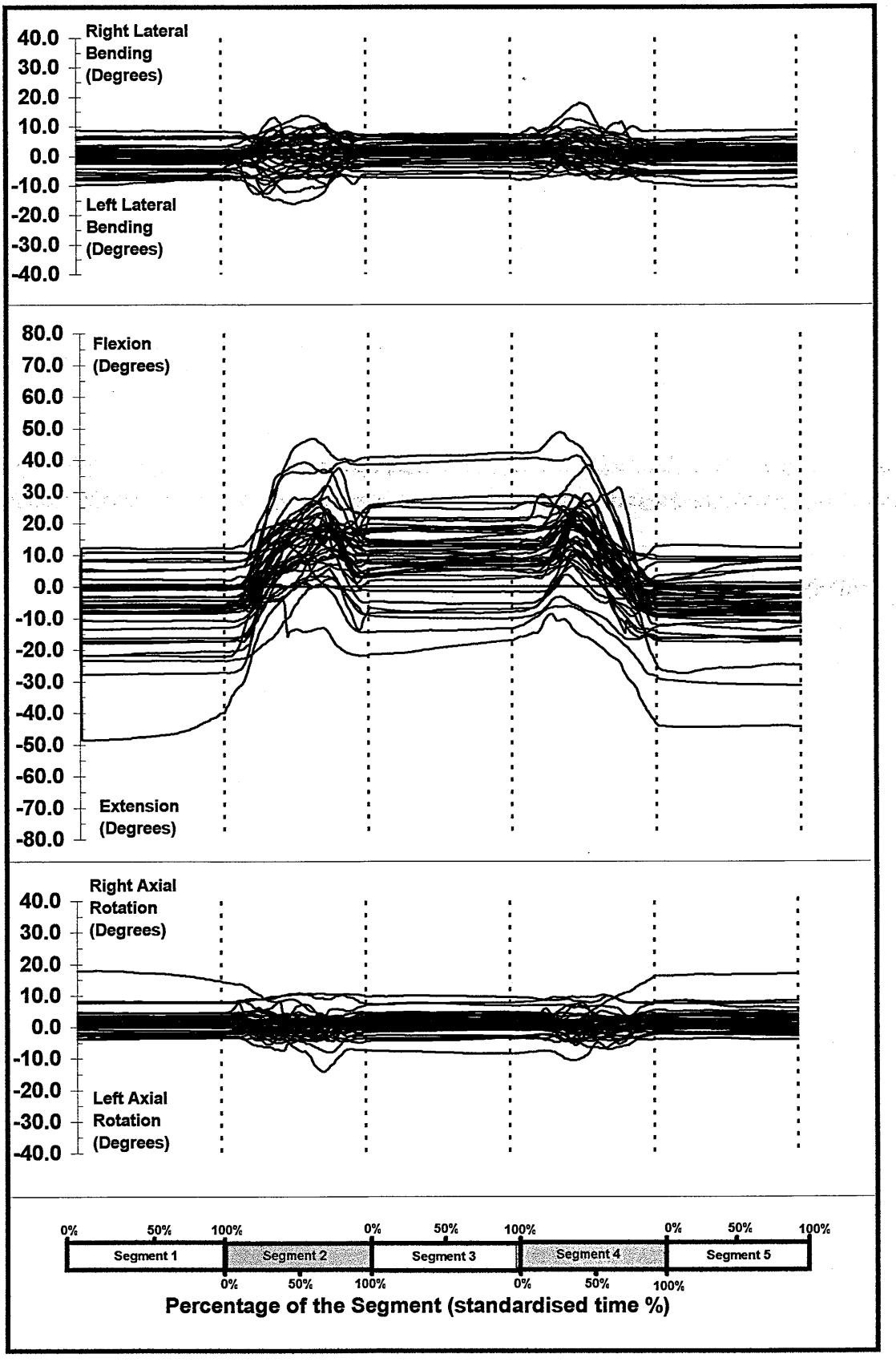


Figure 11.14 Interpolated individual plots of 41 patients performing the functional movement of sitting down and standing up from a stool.

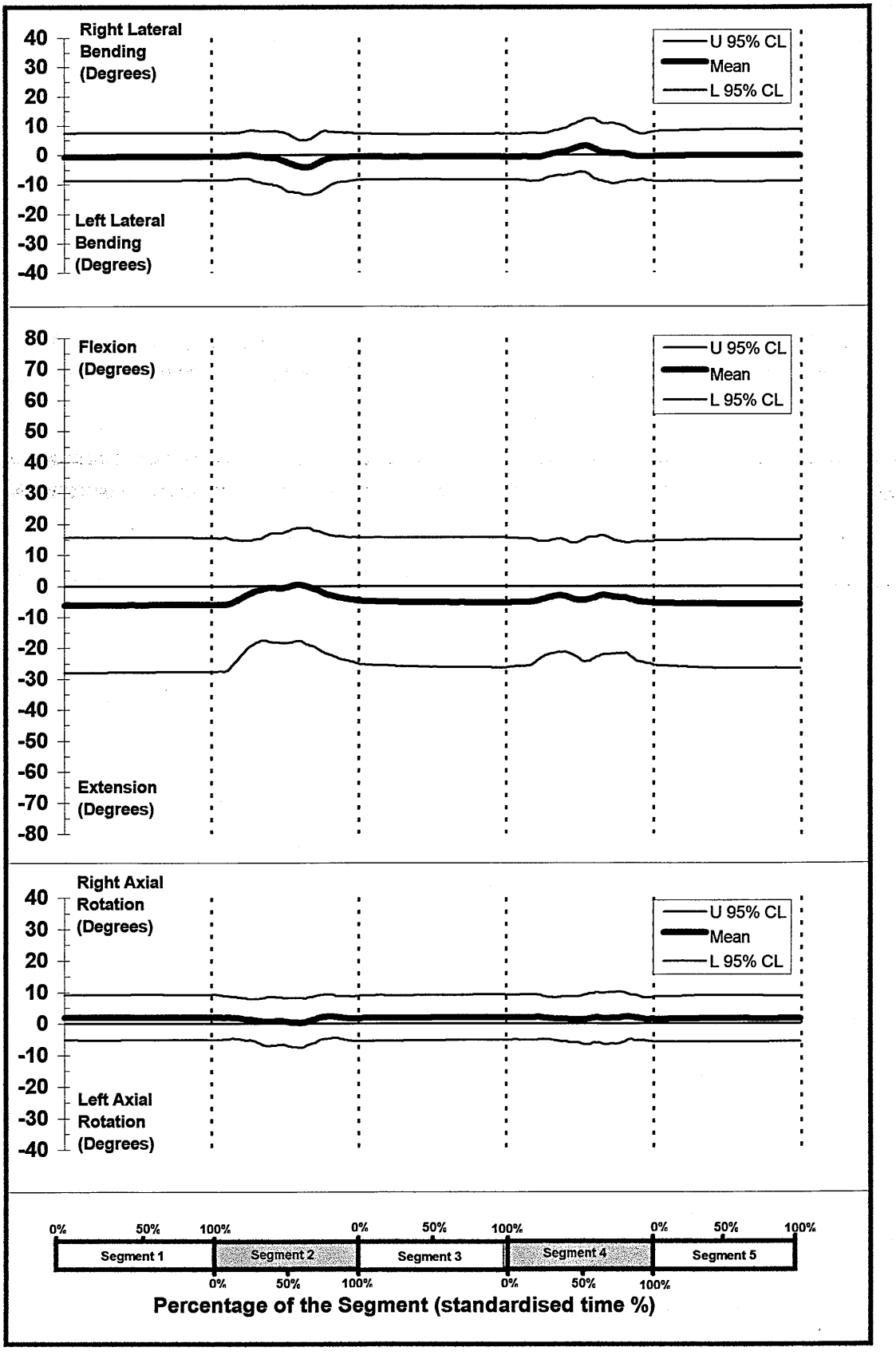


Figure 11.15 Interpolated mean plot of 41 patients performing the functional movement of going up and down a step.

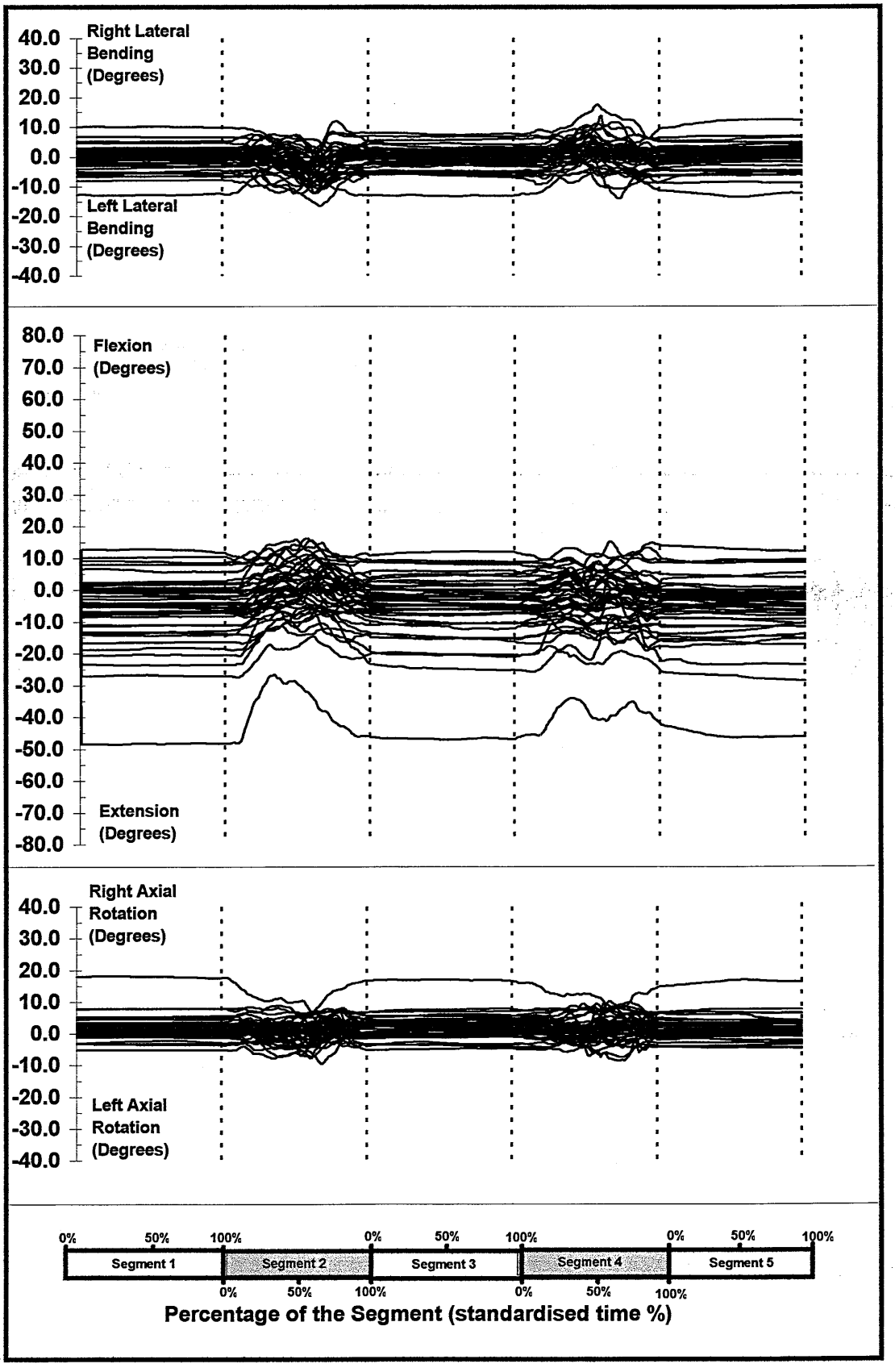


Figure 11.16 Interpolated individual plots of 41 patients performing the functional movement of going up and down a step.

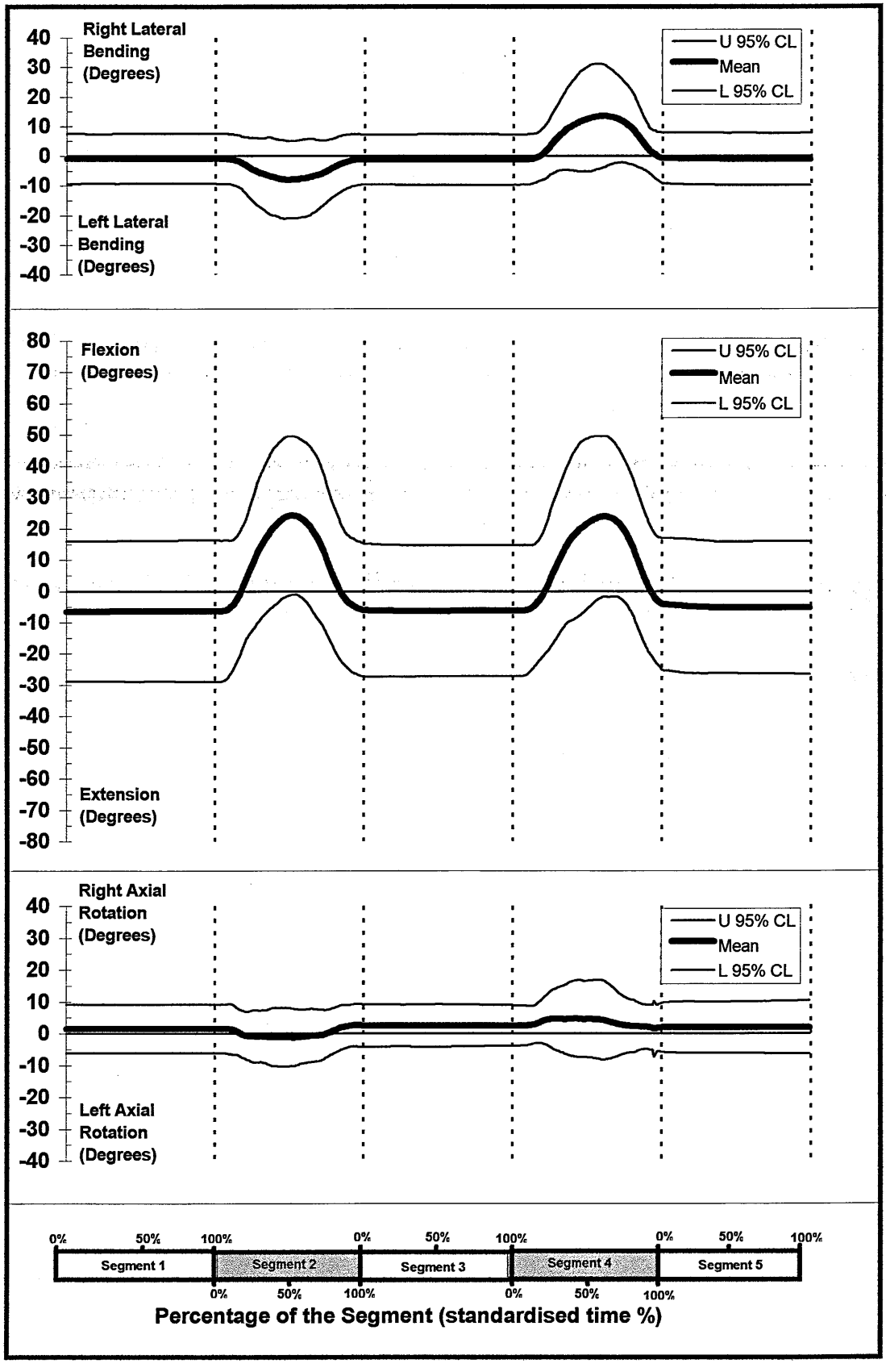


Figure 11.17 Interpolated mean plot of 41 patients performing the functional movement of picking up a box at the left and putting it down at the right.

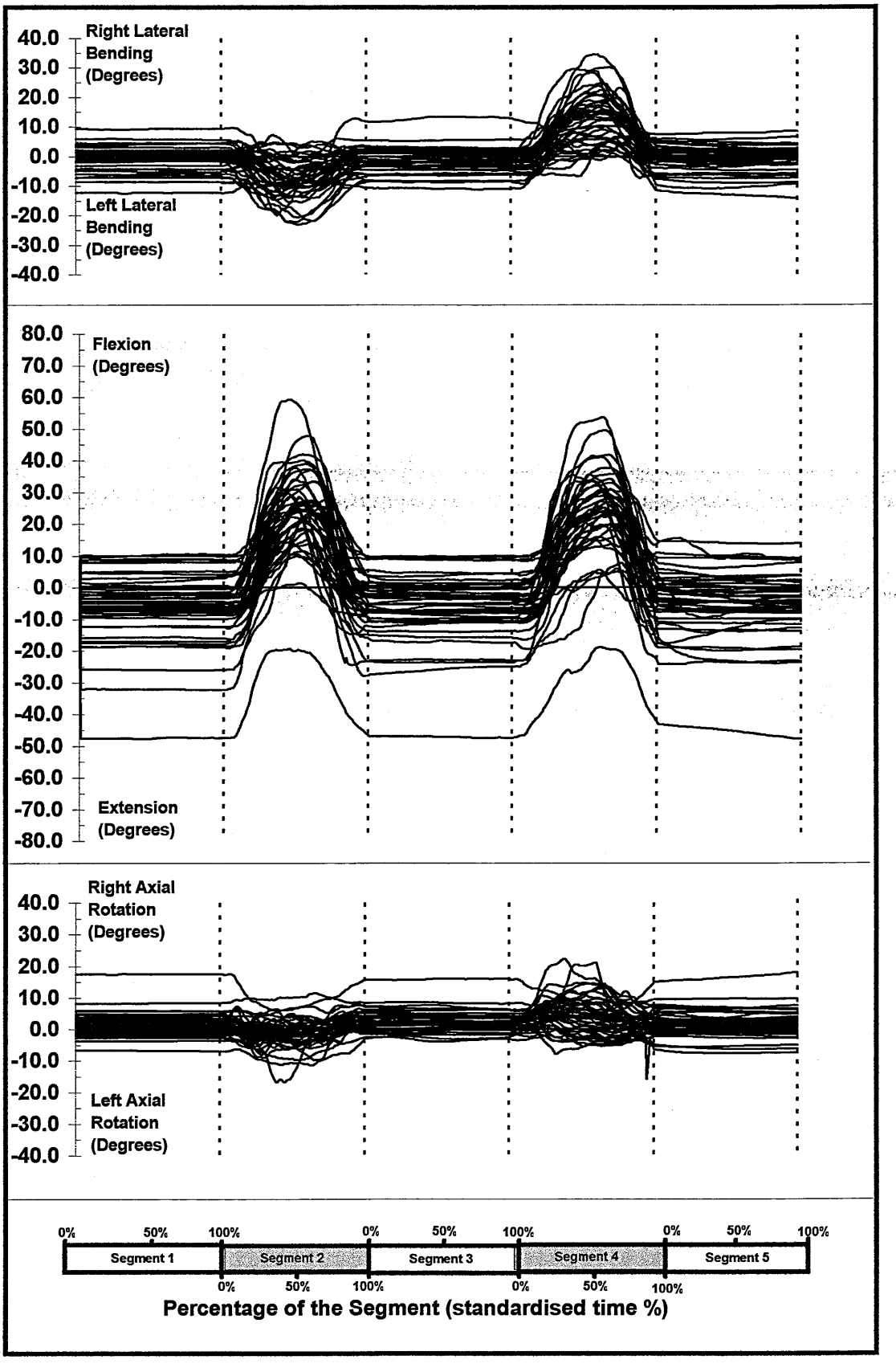


Figure 11.18 Interpolated individual plots of 41 patients performing the functional movement of picking up a box at the left and putting it down at the right.

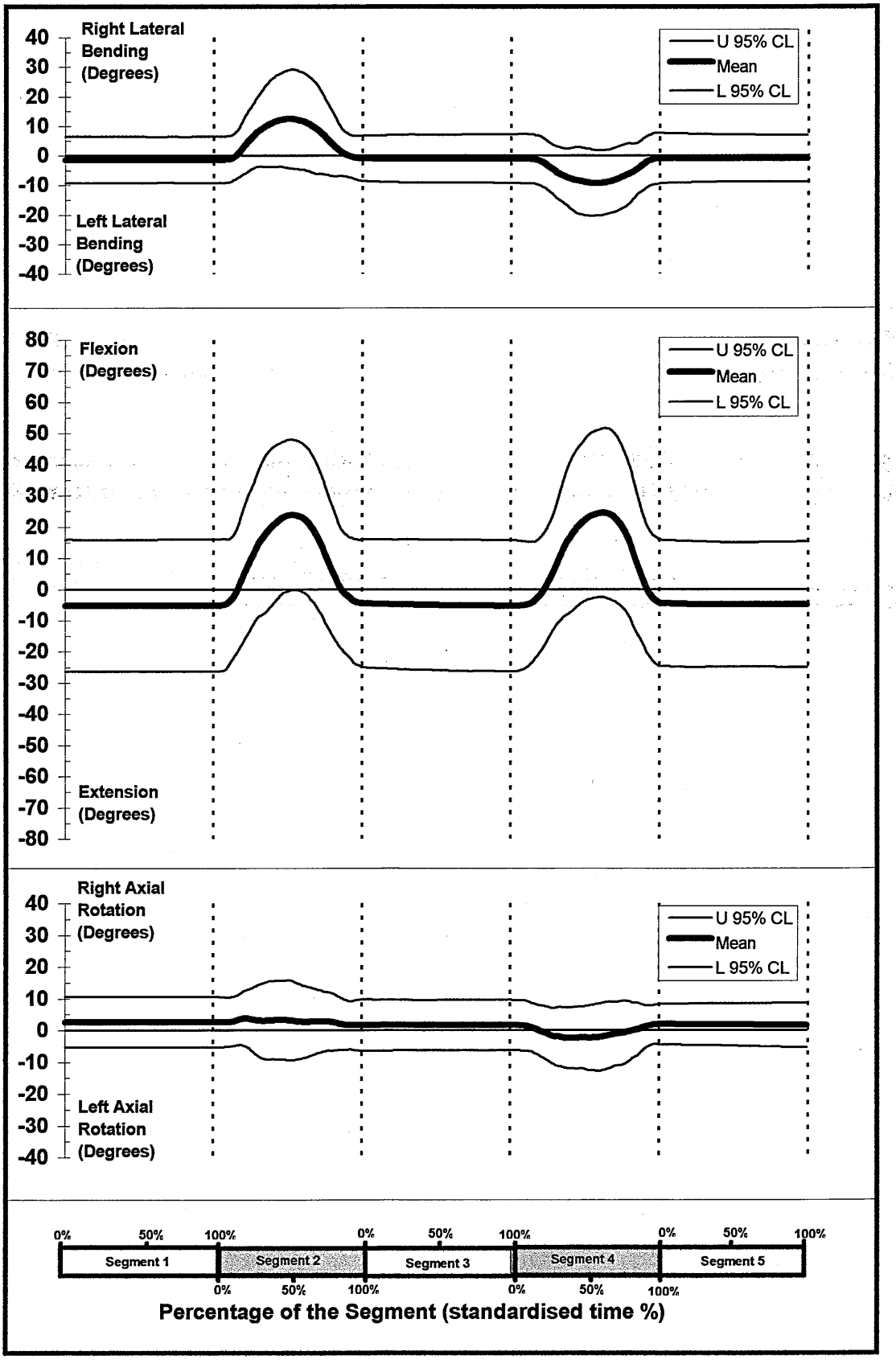


Figure 11.19 Interpolated mean plot of 41 patients performing the functional movement of picking up a box at the right and putting it down at the left.

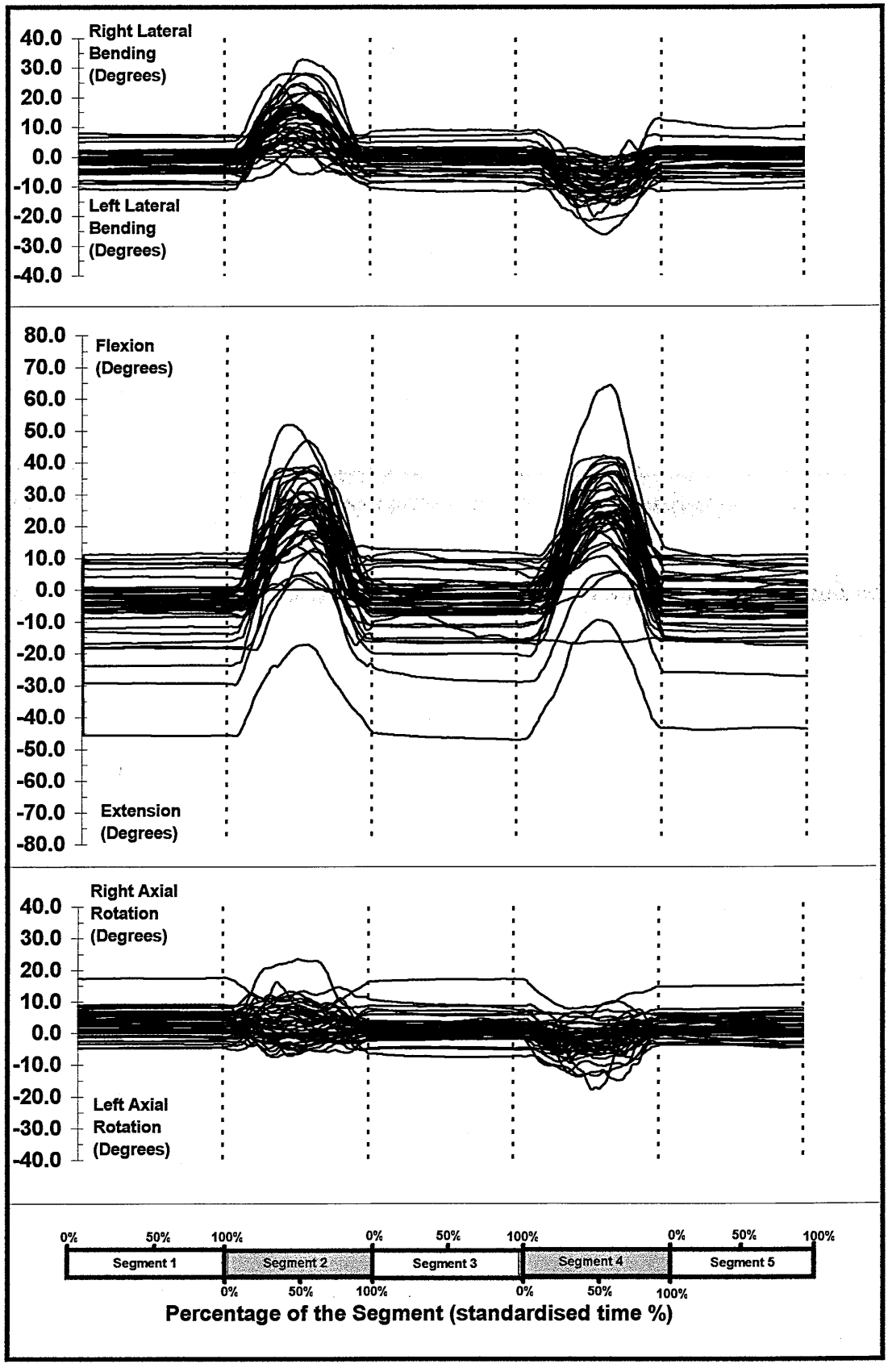


Figure 11.20 Interpolated individual plots of 41 patients performing the functional movement of picking up a box at the right and putting it down at the left.

11.2.2 Lumbar mobility excursion values in low back patients (functional movements)

A summary of the 3 dimensional excursions values for the 4 functional movements (sitting down and standing up from a stool, going up and down a step, picking up a box at the left side and putting it down at the right and picking up a box at the right and putting it down at the left) is provided in tables 11.5 - 11.8.

Sitting down and standing up from a stool	Lateral Bending (Degrees)	Flexion-Extension (Degrees)	Axial Rotation (Degrees)
Mean	8.6	29.2	6.3
Standard Deviation	5.2	8.8	3.2
Upper 95% Confidence Level	18.7	46.5	12.5
Lower 95% Confidence Level	-1.6	11.9	0.2
Maximum Value in Group	30.3	50.9	16.3
Minimum Value in Group	3.1	14.6	2.1
Median	6.6	28.5	5.8
97.5th percentile	23.9	44.6	12.8
2.5th Percentile	3.6	14.9	2.7

Table 11.5: 3-Dimensional kinematic pattern excursion values for the functional activity of sitting down on a stool and standing up

Going up and down a step	Lateral Bending (Degrees)	Flexion-Extension (Degrees)	Axial Rotation (Degrees)
Mean	10.7	10.8	7.2
Standard Deviation	4.4	4.7	2.9
Upper 95% Confidence Level	19.6	20.1	12.8
Lower 95% Confidence Level	2.0	1.5	1.6
Maximum Value in Group	25.9	22.1	12.8
Minimum Value in Group	2.7	3.8	2.1
Median	10.7	10.3	6.7
97.5th percentile	18.1	20.1	12.7
2.5th Percentile	4.2	4.4	3.0

Table 11.6: 3 Dimensional kinematic pattern, excursion value for the functional activity of going up a step and stepping down.

Picking up a box at the left side	Lateral Bending (Degrees)	Flexion-Extension (Degrees)	Axial Rotation (Degrees)
Mean	24.3	35.5	11.6
Standard Deviation	10.7	10.1	6.6
Upper 95% Confidence Level	45.2	55.3	24.6
Lower 95% Confidence Level	3.4	15.6	-1.4
Maximum Value in Group	48.8	56.8	38.0
Minimum Value in Group	7.1	14.4	4.1
Median	22.2	34.7	9.1
97.5th percentile	48.5	55.5	25.1
2.5th Percentile	8.1	18.3	4.1

Table 11.7: 3 Dimensional kinematic pattern, excursion values for the functional activity of picking up a box at the left side and putting it down at the right

Picking up a box at the right side	Lateral Bending (Degrees)	Flexion-Extension (Degrees)	Axial Rotation (Degrees)
Mean	24.0	34.9	11.4
Standard Deviation	10.7	11.0	6.7
Upper 95% Confidence Level	44.9	56.3	24.5
Lower 95% Confidence Level	3.0	13.4	-1.7
Maximum Value in Group	59.1	65.1	34.3
Minimum Value in Group	7.4	12.6	4.8
Median	20.8	33.5	9.0
97.5th percentile	45.4	53.7	28.7
2.5th Percentile	7.8	19.1	5.1

Table 11.8: 3 Dimensional kinematic pattern, excursion values for the functional activity of picking up a box at the right side and putting it down at the left side.

A summary of the main and coupled excursion values during the functional activities is provided in table 11.9.

Functional Activity	Primary Movement	Main Excursion Values Primary Movement (Degrees)	Coupled Movements	Main Excursion Values Coupled Movement (Degrees)
Sitting down & standing up	Flexion	29.2 (8.8)	Lateral Bending Axial Rotation	8.6 (5.2) 6.3 (3.2)
Going up and down a step	Flexion	10.8 (4.7)	Lateral Bending Axial Rotation	10.7 (4.4) 7.2 (2.9)
Picking up a box at the left side and putting it down at the right	Flexion	35.5 (10.1)	Lateral Bending Axial Rotation	24.3 (10.7) 11.6 (6.6)
Picking up a box at the left side and putting it down at the right	Flexion	34.9 (11.0)	Lateral Bending Axial Rotation	24.0 (10.7) 11.4 (6.7)

Table 11.9: Summary of primary and coupled movements in 41 patients during 4 functional movements.

11.2.3 Analysis of differences in excursion values between low back pain patients and healthy subjects (functional movements).

The excursion values for 4 functional movements, obtained by the healthy subject sample (n=100) were compared to the excursion values obtained by LBP-patients (n=41).

Functional Movement	Primary Movement	Value Patients	Value Healthy Subjects	Coupled Movements	Value Patients	Value Healthy Subjects
Sitting down Standing up	Flexion	29.2	32.9	Lateral Bend	8.6	5.9
				Axial Rotation	6.3	4.9
Going up and down a step	Flexion	10.8	13.9	Lateral. Bend	10.7	11.4
				Axial Rotation	7.2	6.7
Picking up a box at the left side and putting it down at the right	Flexion	35.5	47.3	Lateral Bend.	24.3	35.0
				Axial Rotation.	11.6	15.2
Picking up a box at the left side and putting it down at the right	Flexion	34.9	47.3	Lateral. Bend	24.0	34.5
				Axial Rotation	11.4	15.5

Table 11.10 Comparison of excursion mobility between patients and healthy subjects-groups (primary and coupled movements).

Table 11.11 gives a summary of the changes (increase or decrease) occurring in the excursion values of both coupled and primary movements in 4 functional activities. Comparison of changes occurring between healthy subjects and low back pain patients.

Functional Activity	Flexion	Lateral Bend	Axial rotation
Sitting down & standing up	Decreased 11.2%	Increased 31.3%	Increased 22.2%
Going up and down a step	Decreased 22.3%	Decreased 5.3 %	Increased 7.4%
Picking up a box at the left side and putting it down at the right	Decreased 24.9%	Decreased 29%	Decreased 23%
Picking up a box at the left side and putting it down at the right	Decreased 26.4%	Decreased 30.4%	Decreased 24.4%

Table 11.11: Summary of changes in occurring in excursion values between the healthy subjects and patients groups

Sitting down and Standing up from a stool:

The LBP-patient-group (figure 11.13) displayed the same kinematic pattern as the healthy subjects group (figure 10.26) when performing the functional movement of sitting down and standing up from a stool. However, the LBP-patient-group showed an increase in compensatory movements of lateral bending (31.3%) and axial rotation (22.2%) compared to the healthy subject group (8.6 degrees versus 5.9 degrees in lateral bending and 6.3 versus 4.9 in axial rotation). Despite an increase in excursion values, during the compensatory movements, the excursion value of the primary movement of flexion was reduced by 11.2% (29.2 degrees in the patients-group versus 32.9 degrees in the healthy subjects group). Furthermore the primary and the compensatory movements displayed signs of disruption and were not executed in the same smooth, uniform way as for the healthy

subjects suggesting that the patients group showed more apprehension and had more difficulties performing the movements compared to the healthy subjects.

Going up and down a step (left foot first)

The kinematic pattern observed during the functional movement of going up and down a step was similar for the patients group (figure 11.14) and the healthy subjects group (figure 10.27). The LBP-patient-group showed a slight decrease in the coupled movement of lateral bending (5.3%) (10.7 degrees in the patients group versus 11.4 in the healthy subjects group) but a slight increase in axial rotation values (7.4%) (7.2 degrees in the patient group versus 6.7 degrees in the healthy subjects group). The primary movement excursion value was reduced in the patient-group by 22.3 % (13.9 degrees versus 10.8 degrees).

Picking up a box at the left side and putting it down at the right side

The LBP-patient-group (figure 11.17) displayed the same kinematic pattern as the healthy subjects group (figure 10.30) when performing the functional movement of sitting down and standing up from a stool. However, the LBP-patient-group showed a decrease in the compensatory movements of lateral bending (29%) and axial rotation (23%) compared to the healthy subject group (24.3 degrees versus 35.0 degrees in lateral bending and 11.6 versus 15.2 in axial rotation). A decrease in excursion values was also apparent, during the primary movement of flexion which was reduced by 24.9% (35.5 degrees versus 47.3 degrees).

Some small disruptions were observed from the pattern observed in the healthy subjects group.

Picking up a box at the right side and putting it down at the left side

Also during the mirror movement of picking up a box displayed the patient-group (figure 11.19) a nearly identical kinematic pattern as the healthy subjects group (figure 10.32). The LBP-patient-group showed a decrease in the compensatory movements of lateral bending (30.4%) and axial rotation (26.4%) compared to the healthy subject group (24.0 degrees versus 34.5 degrees in lateral bending and 1146 versus 15.5 in axial rotation). A decrease in excursion values was also apparent, during the primary movement of flexion which was reduced by 26.2% (34.9 degrees versus 47.3 degrees).

11.2.4 Statistical analysis of the differences between LBP-patients and healthy subjects (functional movements)

Table 11.12 presents the statistical analysis of the 4 functional movements. T-tests for independent samples, (2-tailed) were used to test the null hypothesis of no differences between the healthy subject and patient groups for both primary and coupled movements. Statistically significant differences in excursion values were found in both primary and coupled movements during "picking up a box left and right". In "sitting down and standing up from a stool" significant differences were found in the coupled movements but not in the primary movement (flexion). The opposite was found "in going up and down a step" with no significant differences in the coupled movements but the primary movement of flexion significantly reduced in the patient group.

Table 11.11 displayes the statistical analysis of the 4 functional movements (differences between 100 healthy subjects and 41 LBP-patients in primary and coupled movements).

Functional Movement	Movement analysed	t-value	P-value	Significance	95 5% Confidence Interval of the Mean	
					Lower	Upper
Sitting down and standing up	**Lateral Bending**	-3.16	= 0.03	Yes	-4.358	-0.965
	Flexion	1.96	= 0.055	No	-0.86	7.491
	Axial Rotation	-2.78	= 0.008	Yes	-2.549	-0.411
Going up and down a step	**Lateral Bending**	0.81	= 0.419	No	-0.902	2.156
	Flexion	3.56	= 0.001	Yes	1.370	4.802
	Axial Rotation	-0.92	= 0.359	No	-1.485	0.541
Picking up a box at left side	**Lateral Bending**	5.418	< 0.001	Yes	6.781	14.575
	Flexion	7.241	< 0.001	Yes	8.618	15.092
	Axial Rotation	3.008	= 0.003	Yes	1.243	6.013
Picking up a box at right side	**Lateral Bending**	5.160	< 0.001	Yes	6.471	14.511
	Flexion	7.175	< 0.001	Yes	9.096	16.017
	Axial Rotation	3.295	= 0.001	Yes	1.661	6.644

Table 11.12 Statistical analysis of the 4 functional movements (differences between 100 healthy subjects and 41 LBP-patients in primary and coupled movements).

Summary: Differences between patients and healthy subjects in functional movements

- The low back pain patient group showed, in general, the same kinematic pattern as the healthy subject group when performing functional movements. No different coupled movement patterns were observed.

- The patient group showed an overall decrease in excursion values in all primary movements and in all coupled movements except for sitting down and standing up from a stool where there was an increase in the values for the coupled movements and for going up and down a step where there was an increase in axial rotation.

- While patterns where similar excursions differed substantially. Where excursion was large in healthy subjects this tended to be reduced in patients and where little excursion was used by the healthy group this tended to be increased in the low back pain patients group.

Chapter 12 Results: Randomised Clinical Trial

12.1 Effect of Mobilisations on Pain

The immediate effect of a mobilisation treatment on patients pain level was measured using a Visual Analogue Pain Intensity-Scale (V.A.S), where 0 mm relates to no pain and 100 mm relates to maximal pain.

Figure 12.1 displays the V.A.S-scores for all the 41 patients before and after a mobilisation treatment.

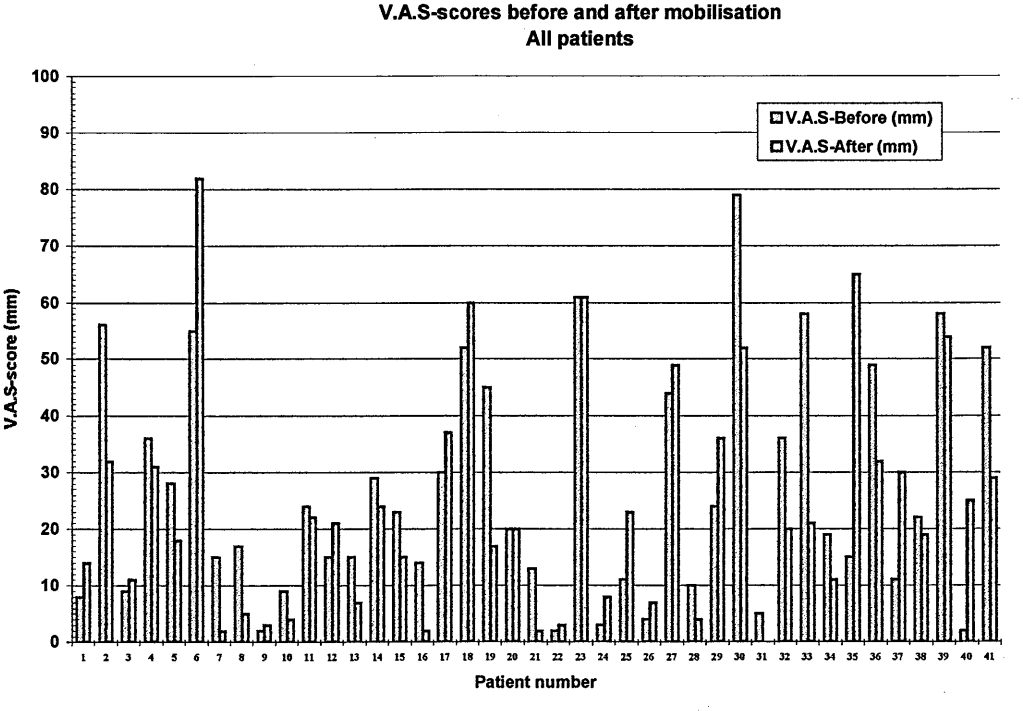


Figure 12.1 VAS-scores before and after mobilisation for all 41 patients

The mean V.A.S score (SD) for all 41 patients before mobilisation was 26.3 (16.9) mm. This score was reduced to 23.9 (15.5) mm after treatment. Although V.A.S-data are recorded in mm, pain scales are, for this study, considered to be on an ordinal level consequently non-parametrical (distribution-free) statistical tests were applied to the data. Distribution free statistical analysis using a Wilcoxon Matched-Pairs, Signed-Ranks Test

(2-tailed) supported the null hypothesis of no difference in V.A.S-scores before and after a mobilisation treatment (p= 0.156).

The effect of a mobilisation treatment on the patients' pain experience was analysed for the 2 patient groups included in the randomised controlled trial i.e. the group who received the treatment after the second of the three measurements (to be called the "delayed intervention group") and the group which got the treatment intervention immediately after the first measurement (to be called the "intervention group")

Figure 12.3 displays how the V.A.S-scores varied before and after a mobilisation treatment in the delayed intervention group (n=21).

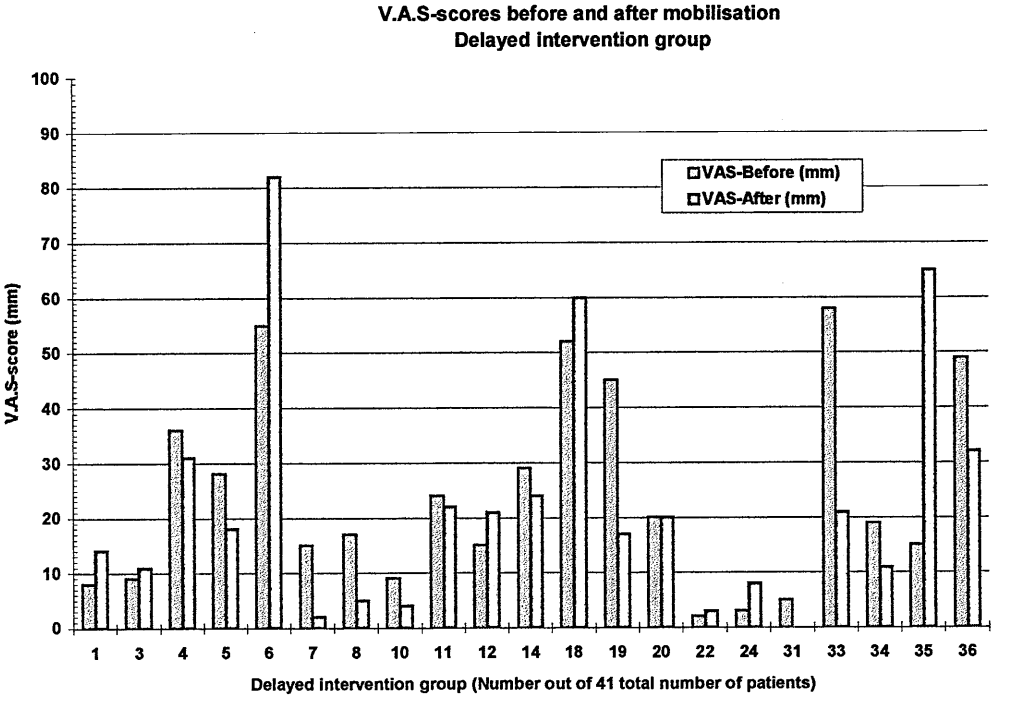


Figure 12.3 V.A.S-scores before and after mobilisation, delayed intervention group

The mean V.A.S score for all 21 patients in the delayed intervention group, before mobilisation was 24.4 (17.9) mm. This score was reduced to 22.4 (21.7) mm after treatment.

Distribution free statistical analysis using a Wilcoxon Matched-Pairs, Signed Ranks Test (2-tailed) supported the null-hypothesis of no difference in V.A.S-scores before and after a mobilisation treatment (p=0.295).

Figure 12.4 displays how the V.A.S-scores varied before and after a mobilisation treatment in the intervention group (n=20).

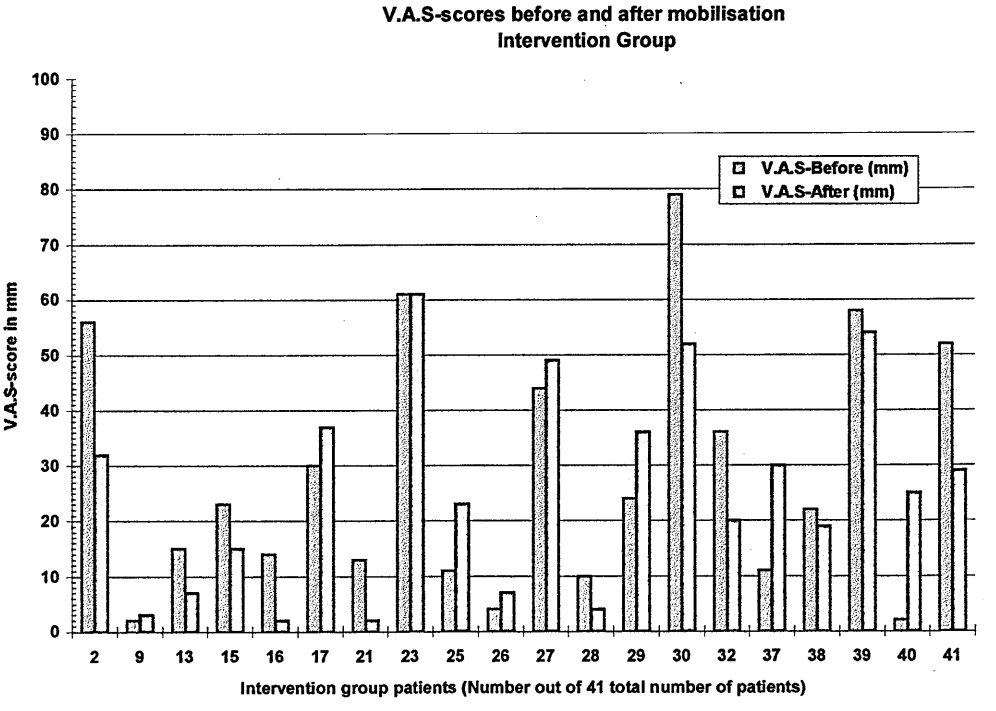


Figure 12.4 V.A.S-scores before and after mobilisation, Intervention group

The mean V.A.S score for all 20 patients in the intervention group, before mobilisation was 28.3 (22.6) mm. This score was reduced to 25.3 (18.6) mm after treatment.

Distribution free statistical analysis using a Wilcoxon Matched-Pairs, Signed Ranks Test (2-tailed) supported the null-hypothesis of no difference in V.A.S-scores before and after a mobilisation treatment (p=0.334).

In order to evaluate the immediate effect of a mobilisation treatment in acute low back patients, 18 patients were selected where the pain duration from onset was less than 6 weeks.

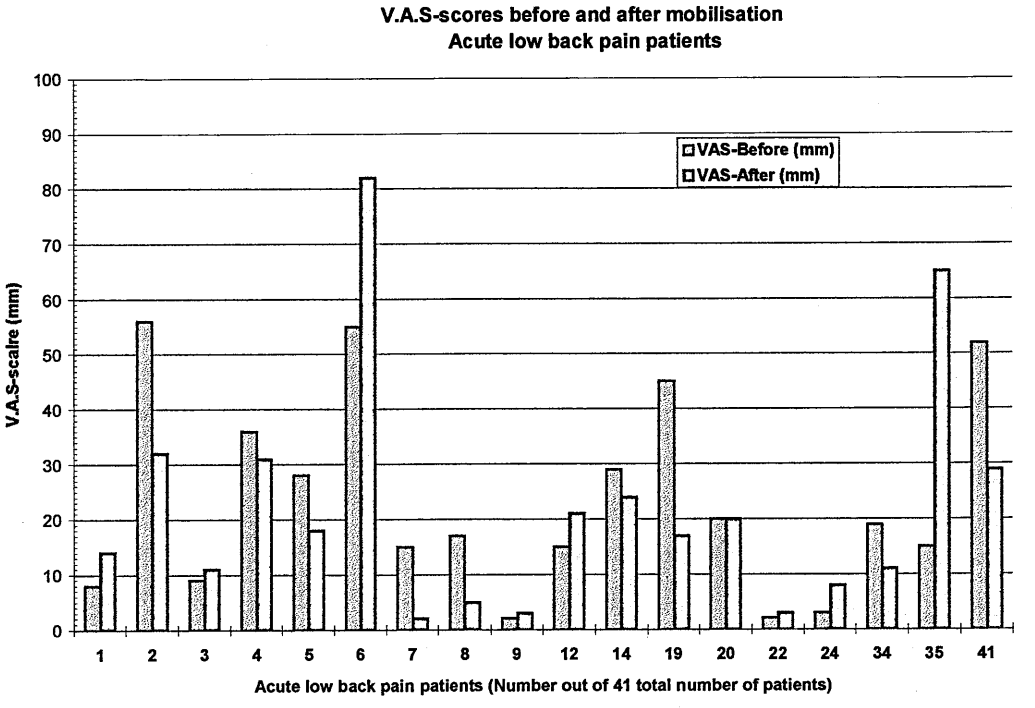


Figure 12.5 V.A.S scores before and after mobilisation, Acute Low Back Pain patients

The mean V.A.S-score for this group was 23.7 (15) mm before treatment and 22.0 (14.6) mm after treatment. Distribution free statistical analysis using a Wilcoxon Matched-Pairs, Signed-Ranks Test (2-tailed) supported the null hypothesis of no difference in V.A.S-scores before and after a mobilisation treatment ($p= 0.381$).

The remaining 23 patients had pain for more than 6 weeks and were considered as subacute Figure 12.6 displays the V.A.S-scores in the subacute patient group

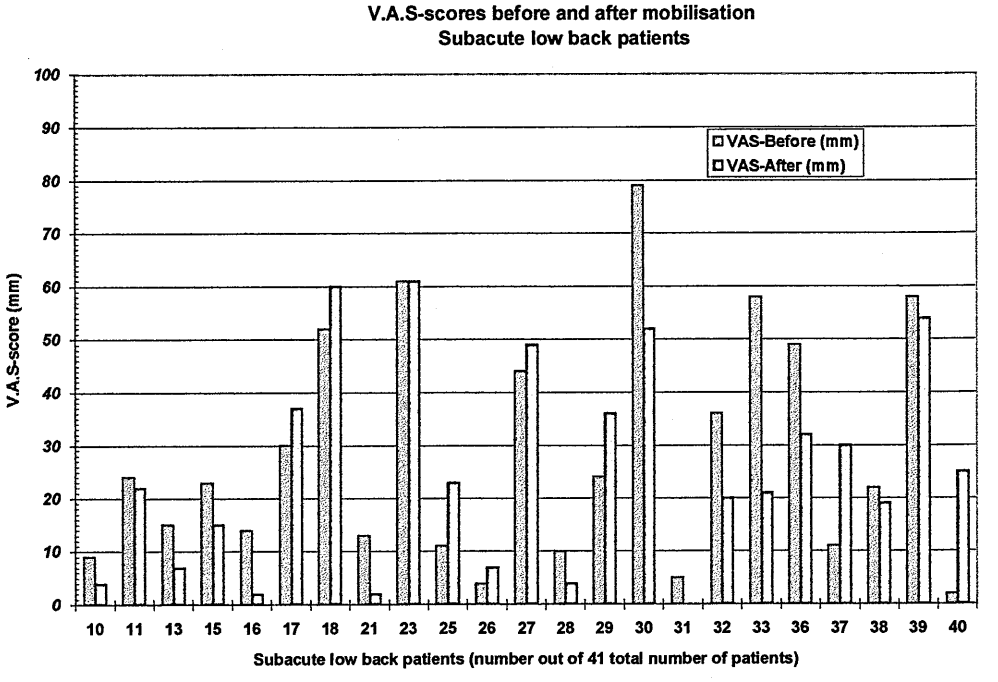


Figure 12.6 V.A.S scores before and after mobilisation, subacute low back pain patients

Subacute low back pain patients i.e. patients who had their pain for longer than 6 weeks but less than 12 weeks had a mean pain score of 28.3 (21.9) before mobilisation and 25.3 (19.5) mm after mobilisation.

Distribution free statistical analysis using a Wilcoxon Matched-Pairs Signed-Ranks Test (2-tailed) supported the null hypothesis of no difference in V.A.S-score before and after a mobilisation treatment ($p= 0.346$).

Collins et al (1997) established the relationship between points on the V.A.S-scale and severity of pain. These authors used data from 1080 patients included in randomised clinical trials of various analgesics and found that:

1. of patients reporting moderate pain, 85% scored over 30 mm on the corresponding V.A.S-scale with a mean of 49 mm.
2. of patients reporting severe pain, 85% scored over 54 mm on the corresponding V.A.S-

scale with a mean score of 75 mm.

According to this pain scale the low back pain patients in this study had, on average, "mild" pain although large variations were observed between individual patients.

A comparison of the mean V.A.S-scores for patients in the delayed intervention group and the intervention group indicated that the intervention group reported higher V.A.S-scores (28.3 mm before and 25.3 mm after) compared with the delayed intervention group (24.4 mm before and 22.4 mm after). This mean difference, however was not statistically significant when tested using a Mann-Whitney, Rank Sum Test for Independent Samples with two tails (before mobilisations $p=0.705$ and after mobilisations , $p=0.659$)

A comparison of the mean values for acute and subacute low back patients indicated that subacute low back patients tended to report a higher pain score (28.4 mm before and 25.3 mm after) than acute low back patients (23.7 mm before and 22.0 mm after). However, this mean difference was not significant, tested by a Mann-Whitney, Rank Sum Test for Independent Samples with two-tails (before mobilisations, $p = 0.545$ and after mobilisations $p =0.486$).

In conclusion, low back pain patients in this study presented with a mild degree of pain measured by an Visual Analogue Scale (Collins et al, 1997). When assessed at a statistical level of $p=0.05$ no significant difference in pain response was found between the delayed intervention group and the intervention group. No significant differences in the patients immediate pain response, when assessed statistically at a confidence level of $p=0.05$ levels were found between acute and subacutec low back pain patients before and after a mobilisation treatment. Although differences were observed, the numbers of patients

included did not allow powerful conclusions, at the 0.05 confidence level, for the V.A.S scale measures given the large variation in scores between subjects.

12.2 Effect of a mobilisation treatment on lumbar spinal excursion in 6 gross movements

12.2.1 Lumbar mobility excursion plots in LBP-patients (gross, primary movements)

The mean excursion values of the primary gross movements, for the 2 patient groups and during 3 tests, were plotted in order to compare and contrast the kinematic patterns and excursion values. In addition, the mean normal pattern for 100 healthy subjects was displayed on the same plot for comparison.

The primary gross movements displayed are;

1. Forward Flexion in standing
2. Extension in standing
3. Lateral Bending to the left in standing
4. Lateral Bending to the right in standing
5. Axial Rotation to the left in standing
6. Axial rotation to the right in standing

No substantial differences in excursion values for the coupled movements, were recorded (table 11.3) Therefore it was not deemed relevant to include plots of the coupled movements during the 3 separate tests and for the 2 different groups.

Gross Movement: Forward flexion in standing

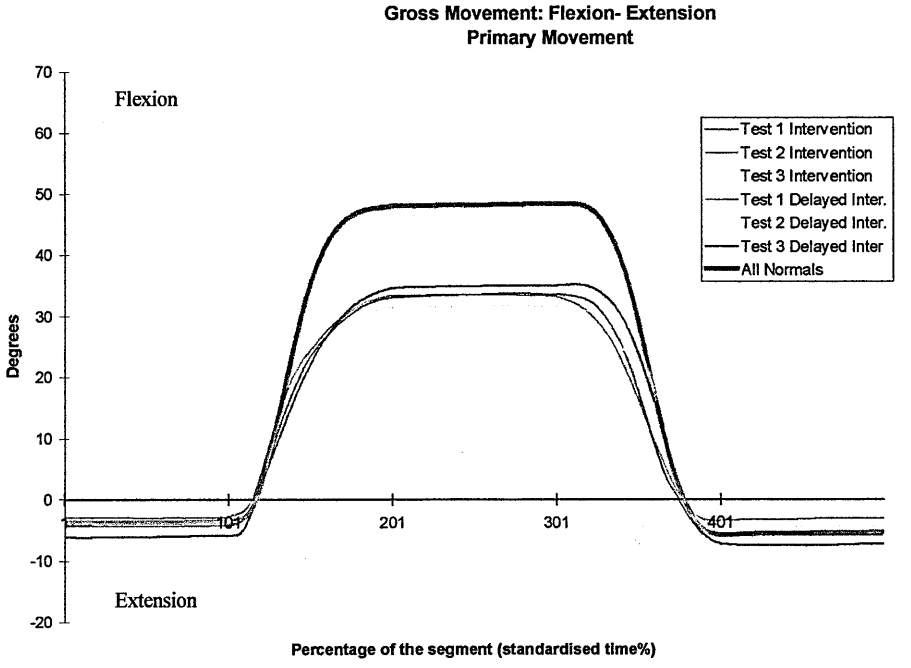


Figure 12.7 Flexion excursion values (primary movement during forward flexion)

Gross Movement: Extension

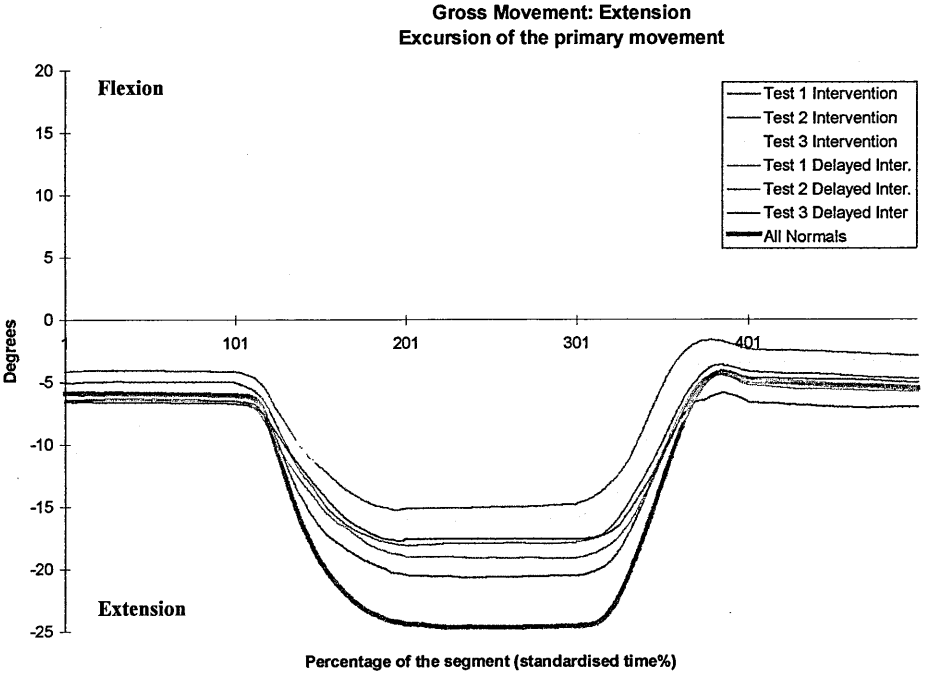


Figure 12.8 Extension excursion values (primary movement during extension)

Gross Movement: Lateral Bending to the Left

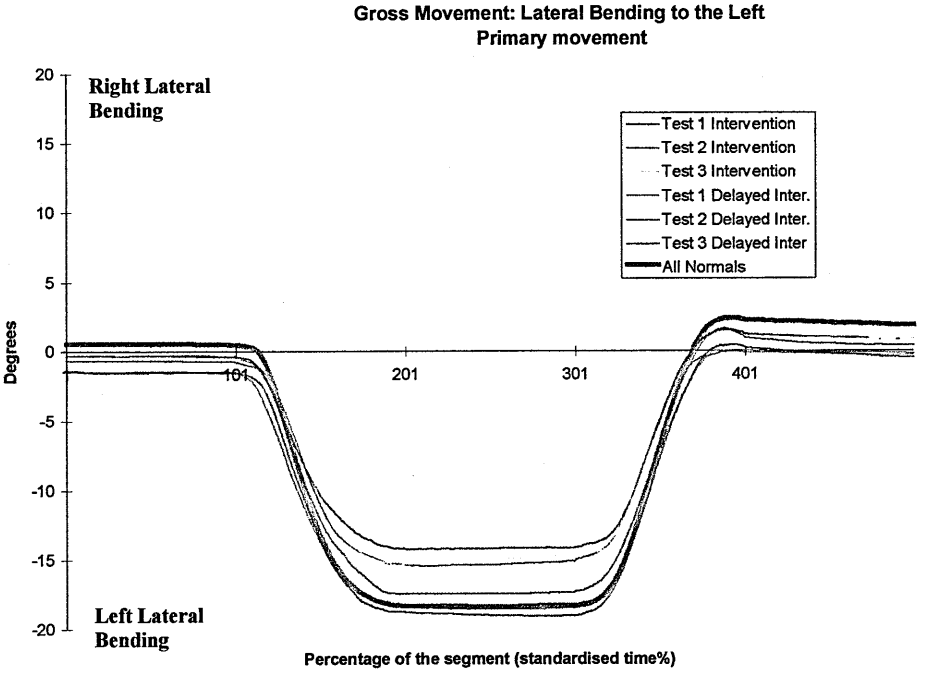


Figure 12.9 Left Lateral bending excursion values (primary movement during lateral bending to the left)

Gross Movement: Lateral Bending to the Right

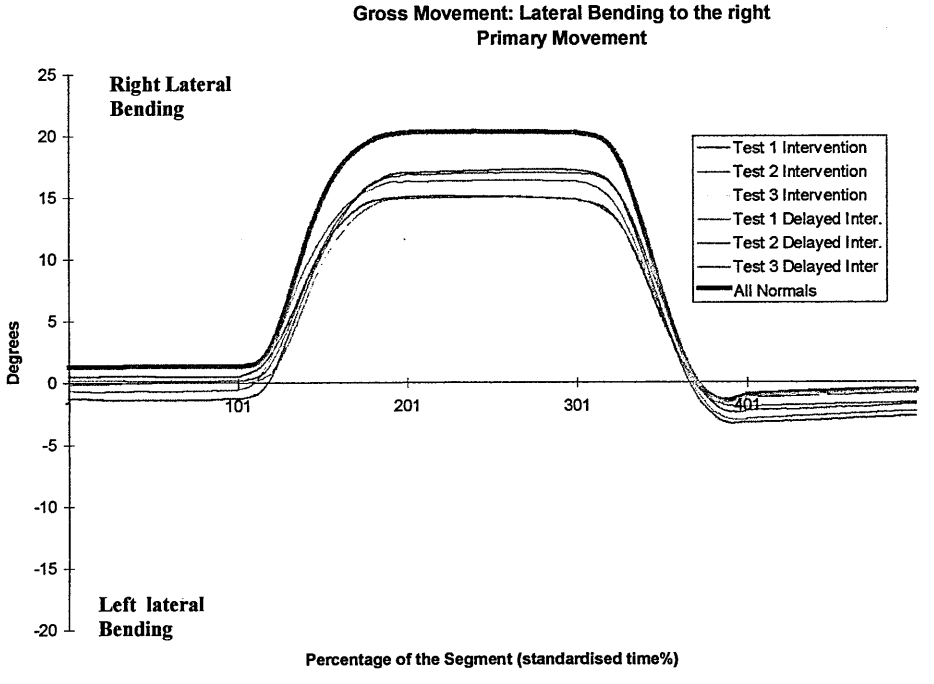


Figure 12.10 Right Lateral bending excursion values (primary movement during lateral bending to the right)

Gross Movement: Axial rotation to the Left

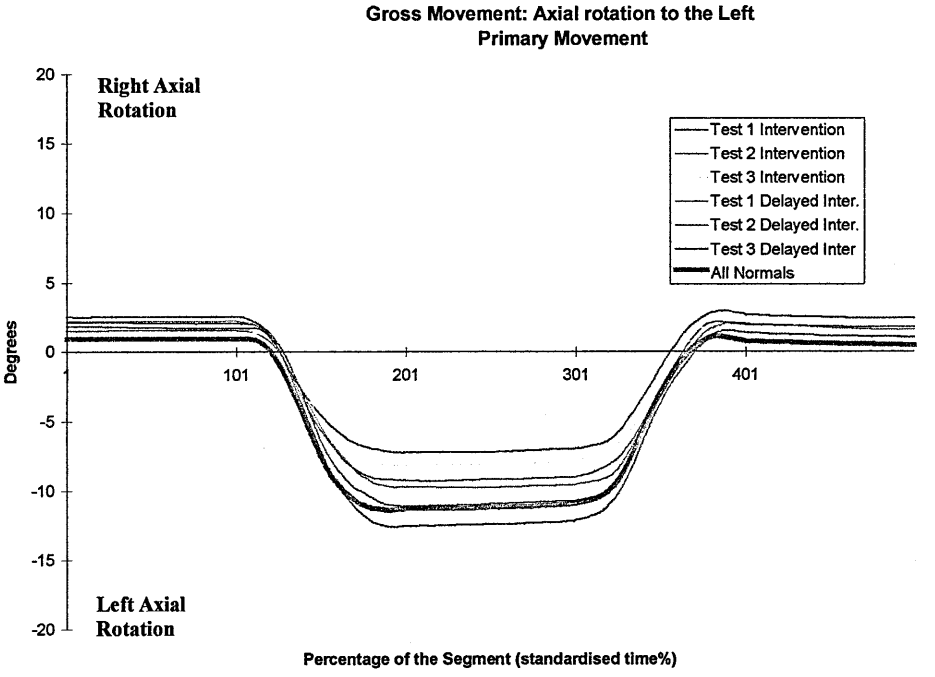


Figure 12.11 Left Axial rotation excursion values (primary movement during axial rotation to the left)

Gross Movement: Axial rotation to the Right

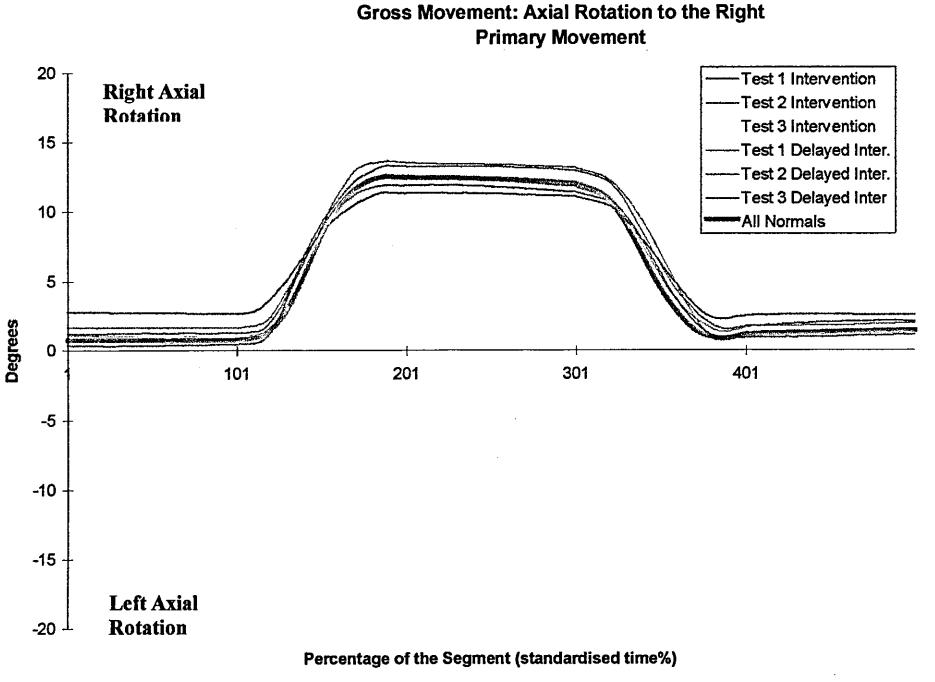


Figure 12.12 Right Axial rotation excursion values (primary movement during axial rotation to the right)

12.2.2 Excursion values (Gross movements)

A detailed presentation (including SD, 95% CL, maximum & minimum values, median and percentiles) of the primary and coupled excursion values during the 6 gross movement and over the 3 different tests is provided in appendixes J (12.1 to 12.6).

Table 12.1 provides a summary of the primary and coupled movements excursions during 6 gross movements and over the 3 different tests. A comparison of all these values with excursion values obtained in healthy subjects is made

Gross movement			Intervention group n=20			Delayed intervention group n=21			Healthy subjects
	Primary Movement	Coupled Movement	Test One (Degrees)	Test Two (Degrees)	Test Three (Degrees)	Test One (Degrees)	Test Two (Degrees)	Test Three (Degrees)	(Degrees)
Forward Flexion		Lateral Bend.	5.4	5.1	4.8	5.4	5.1	5.2	5.5
	Flexion		41.4	39.4	38.1	44.7	39.4	44.4	55.4
		Axial Rotation.	4.5	5.0	4.6	4.7	4.5	4.9	5.9
Extension		Lateral Bend.	3.4	3.4	2.9	2.7	2.9	3.5	3.0
	Extension		14.5	15.6	15.6	16.8	16.6	18.5	23.2
		Axial Rotation	3.6	3.5	3.3	3.4	3.1	4.0	3.6
Lateral Bend Left	Lateral Bend.		16.4	16.4	17.4	19.9	19.8	20.6	21.7
		Flexion-Extension	10.7	11.9	12.1	9.8	10.3	10.7	12.1
		Axial Rotation	4.7	4.1	5.4	5.3	5.5	5.4	4.7
Lateral Bend Right	Lateral Bend.		17.7	18.1	18.4	20.2	20.4	21.5	22.9
		Flexion-Extension	10.1	10.1	9.6	10.5	9.2	10.7	11.8
		Axial Rotation	4.5	4.7	4.7	5.5	5.0	5.1	5.0
Axial Rotation Left		Lateral Bend	4.0	3.9	4.9	4.6	5.2	5.4	5.0
		Flexion-Extension	7.1	7.8	6.9	6.1	7.6	6.8	7.9
	Axial rotation.		11.7	13.0	11.6	13.1	14.3	15.4	14.0
Axial Rotation Right		Lateral Bend.	5.0	4.6	5.0	4.7	4.6	4.7	4.7
		Flexion-Extension	5.1	5.8	5.6	7.1	5.8	7.1	6.7
	Axial rotation.		10.4	13.9	11.9	12.3	13.2	12.9	13.5

Table 12.1 Excursion values in 6 gross movements before and after a mobilisation treatment and comparison with excursions obtained in healthy subjects (primary movements in blue).

Observing the data for the coupled movements from table 12.1, it is apparent that no major differences in values occurred between patient groups and the healthy subjects group. Nor did any major difference occur within the delayed intervention or the intervention group over the 3 tests. Moreover, no major differences could be seen between the 2 groups as a whole.

Because the observed differences in the coupled movements were small no statistical analysis was performed and it was concluded that the coupled movements were not substantially different in amplitude from the healthy subjects.

In contrast to the coupled movements, substantial differences in main excursion values were observed for the primary movements when the patients data were compared to the data of healthy subjects. These differences occurred for both groups and for all three tests on each group (table 12.1). This finding is in agreement with that for the pre-intervention data for the patient group as a whole (table 11.4). The differences in the primary movements were therefore analysed statistically.

12.2.3 Statistical analysis of the randomised controlled trial (gross primary movements)

The differences in mean excursion values from 3 tests were analysed between and within the respective group of low back pain patients. Before subjecting the different samples to statistical analysis all groups were screened for normality by observing an histogram plot of the distribution. None of the distributions were deemed to be significantly skewed, consequently parametric statistics were applied.

A one-way analysis of variance (ANOVA) for repeated measures design was used to test the differences between the means over the three test sessions.

The ANOVA like the t-test is a test for determining whether the differences between means of different samples were drawn from the same population. The differences between more than two means can be tested simultaneously and the pooled within groups variance can serve as an estimated of error in variance.

The null hypothesis tested in this analysis of variance design was:

$$H_0 = \mu_{a1} = \mu_{a2} = \mu_{a3} = \mu_{b1} = \mu_{b2} = \mu_{b3}.$$

Where μ_{a1} represent the mean of the six samples (3 tests on 2 groups).

a = intervention group and b = delayed intervention group.

1 = test 1, 2 = test 2 and 3 = test 3.

The alternative hypothesis (H_1), given in narrative form, is that at least two means differ. If variations between means are due to sampling variability the null hypothesis is accepted, but if the variations are not attributed to sampling fluctuations the null hypothesis is rejected (Currier, 1984).

Where the ANOVA indicated significant differences, post-hoc analysis of the means were conducted to determine where the differences in the means occurred.

Independent or paired t-tests were used for the post-hoc analysis in this study. Where the same group of patients was compared, a paired t-test was used. When the intervention and delayed intervention groups were compared, an independent t-test was used.

The following 11 comparisons between group means were conducted:

1. A1 and B1: Comparing the intervention group before mobilisation to the delayed intervention group before a rest period.

2. A2 and B2: Comparing the intervention group after mobilisation with the delayed intervention group after a rest period.
3. A3 and B3: Comparing the intervention group after mobilisation and a rest period with the delayed intervention group after a rest period and a mobilisation session.
4. A1 and A2: Comparing the intervention group immediately before a mobilisation and immediately after a mobilisation.
5. A1 and A3: Comparing the intervention group immediately before a mobilisation and after a rest period.
6. A2 and A3: comparing the intervention group immediately after a mobilisation treatment and after a rest period.
7. B1 and B2: Comparing the delayed intervention group before and after a rest period.
8. B1 and B3: Comparing the delayed intervention group before a mobilisation treatment and after a rest period.
9. B2 and B3: comparing the delayed intervention group after a rest period and after a mobilisation treatment.
10. A1 and B2: Comparing the intervention group before a mobilisation treatment and the delayed intervention group after a rest period.
11. A2 and B3: Comparing the intervention group after a mobilisation treatment and the delayed intervention group after a mobilisation treatment.

A Bonferroni correction was applied to correct for the repeated t-test application i.e. an overall alpha-level of 0.05 was divided by 11 to give an alpha level for each test of 0.004.

Table 12.2 displays the results of 6 different analysis of variances applied to the 6 gross movements for intervention and delayed intervention groups.

	F-Ratio	P-Value	Significance
Forward Flexion			
Tests of Within Subjects Effects	4.464	0.015	**Yes**
Interaction	3.363	0.40	No
Test of Between Subjects Effects	0.646	0.426	No
Extension			
Tests of Within Subjects Effects	1.662	0.196	No
Interaction	0.766	0.468	No
Test of Between Subjects Effects	0.603	0.442	No
Lateral Bend to the Left			
Tests of Within Subjects Effects	1.330	0.270	No
Interaction	0.014	0.987	No
Test of Between Subjects Effects	2.754	0.105	No
Lateral Bend to the Right			
Tests of Within Subjects Effects	1.483	0.233	No
Interaction	0.227	0.797	No
Test of Between Subjects Effects	1.626	0.210	No
Axial Rotation to the Left			
Tests of Within Subjects Effects	1.871	0.161	No
Interaction	2.029	0.138	No
Test of Between Subjects Effects	1.744	0.194	No
Axial Rotation to the Right			
Tests of Within Subjects Effects	6.746	0.02	**Yes**
Interaction	2.488	0.90	No
Test of Between Subjects Effects	0.195	0.661	No

Table 12.2: Analysis of Variance for 6 gross movements

From these analyses of variance it follows that in two out of the six gross movements a significant difference was present and consequently a post-hoc analysis was required.

Table 12.3 and 12.4 provide a summary of 11 post-hoc t-tests. These tests were performed on the gross movements of forward flexion and axial rotation to the right as these movements yielded a significant p-value during the analysis of variance (table 12.2).

Forward Flexion

Combination	Mean Difference	Lower 95% Confidence of the Mean	Upper 95% Confidence of the Mean	t-Value	P-Value	Significance
A1 and B1	-3.27	-11.9	5.4	-0.759	0.452	No
A2 and B2	-5.03	-7.78	7.68	-0.13	0.990	No
A3 and B3	-1.01	-4.56	2.53	-0.578	0.567	No
A1 and A2	2.0	-1.53	5.53	1.18	0.251	No
A1 and A3	3.34	0.10	6.59	2.155	0.04	No
A2 and A3	1.34	-1.81	4.49	0.890	0.384	No
B1 and B2	5.22	1.50	8.93	2.93	0.008	No
B1 and B3	0.29	-3.77	4.36	0.151	0.881	No
B2 and B3	-4.92	-8.47	-1.37	-2.89	0.009	No
A1 and B2	1.95	-6.11	10.02	0.489	0.627	No
A2 and B3	-4.97	-13.91	3.95	-1.12	0.267	No

P-values in red if p <0.05, in blue if p <0.004

Table 12.3 Independent and paired t-tests for forward flexion

Axial rotation to the Right

Combination	Mean Difference	Lower 95% Confidence of the Mean	Upper 95% Confidence of the Mean	t-Value	P-Value	Significance
A1 and B1	-1.87	-5.33	1.58	-1.098	0.279	No
A2 and B2	0.69	-3.13	4.52	0.36	0.714	No
A3 and B3	-1.01	-4.56	2.53	0.57	0.567	No
A1 and A2	-3.44	-5.13	-1.75	-4.26	0.000	Yes
A1 and A3	-1.46	-3.09	0.15	-1.88	0.074	No
A2 and A3	1.97	0.15	3.80	2.26	0.035	No
B1 and B2	0.87	-2.52	0.78	-1.09	0.286	No
B1 and B3	0.60	-2.29	1.08	0.74	0.466	No
B2 and B3	0.26	-1.63	2.16	0.29	0.771	No
A1 and B2	0.96	-2.88	4.81	0.50	0.615	No
A2 and B3	-2.74	-6.07	0.57	-1.67	0.103	No

P-values in red if p <0.05, in blue if p <0.004

Table 12.4 Independent and paired t-tests for Axial Rotation to the Right

Tables 12.5 & 12.6 illustrates in which combinations significant differences were found during the gross movements of forward flexion (Table 12.5) and axial rotation to the right (Table 12.6). It displays the main excursion values for the groups concerned during the respective tests. The colour coding illustrates the significance on the alpha levels of 0.05 (red) and 0.004 (blue, Bonferroni correction applied).

Patients Group	Test 1 (Degrees)	Test 2 (Degrees)	Test 3 (Degrees)
Intervention Group (n=20)	41.1		38.1
		39.4	
Delayed intervention group (n=21)	44.7		44.4
		39.4	

Table 12.5 Statistically significant differences between tests in the 2 patients groups (Alpha level 0.05) during the gross movement of forward flexion.

Patients Group	Test I (Degrees)	Test 2 (Degrees)	Test 3 (Degrees)
Intervention Group (n=20)	10.4		11.9
		13.9	
Delayed intervention group (n=21)	12.3		12.9
		13.2	

Table 12.6 Statistically significant differences between test in the 2 patients groups. P-level < 0.05 (red) and < 0.004 (blue) during the gross movement of axial rotation to the right.

12.3 Effect of a mobilisation treatment on lumbar spinal excursions in 4 functional movements

12.3.1 Lumbar mobility excursion plots in LBP-patients (functional movements, primary and compensatory movements)

The mean excursion values for the 2 groups, during 3 tests were plotted for all three angles, in order to compare and contrast the kinematic patterns and excursion values. In addition, the mean normal pattern for 100 healthy subjects was displayed on the same plot for comparison.

This procedure was performed for the following 4 functional movements:

1. Sitting down and standing up from a stool (figure 12.13 - 12.15).
2. Going up and down a step (figure 12.16 - 12.18).
3. Picking up a box at the left hand side and putting it down at the right hand side (figure 12.19 - 12.21).
4. Picking up a box at the right hand side and putting it down at the left hand side (figure 12.22 - 12.24).

Sitting down and standing up from a stool

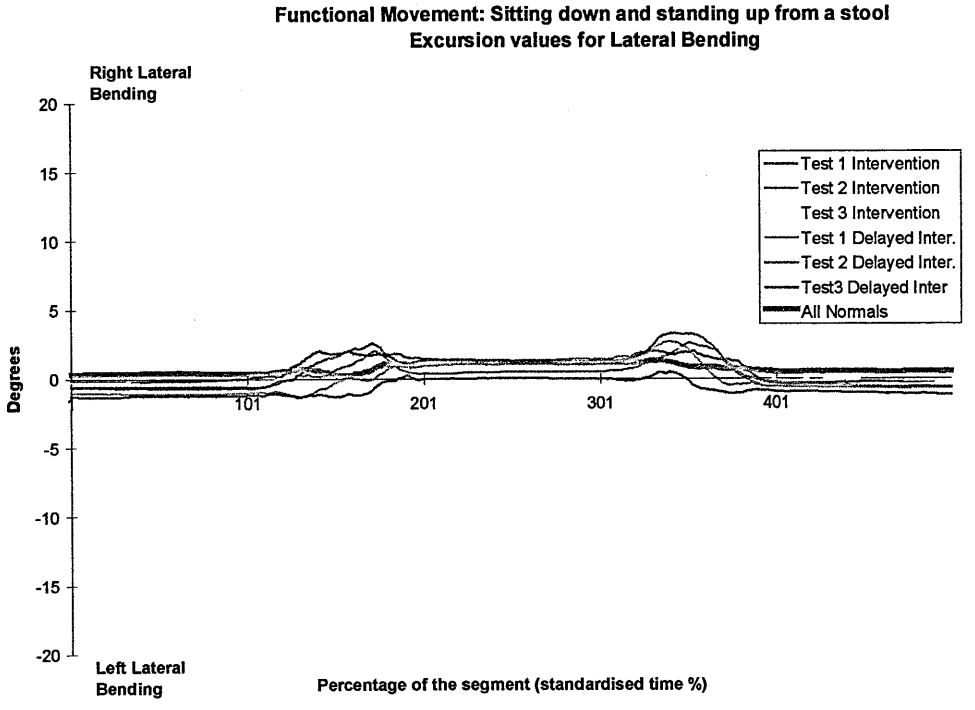


Figure 12.13 Lateral Bending Excursion Values during sitting down and standing up from a stool

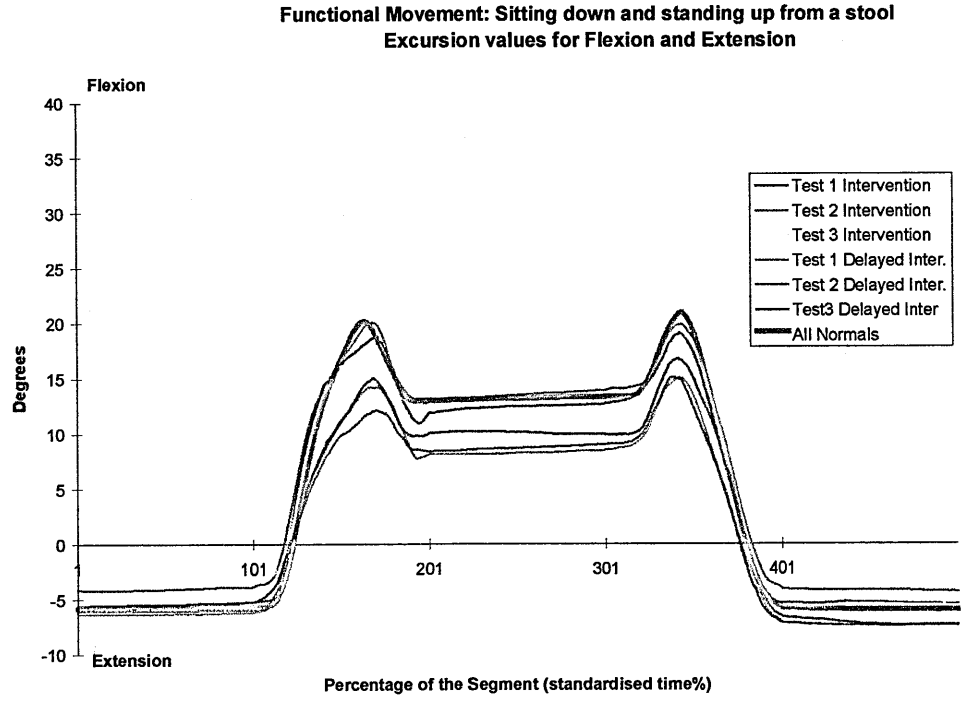


Figure 12.14 Flexion-Extension Excursion Values during sitting down and standing up from a stool

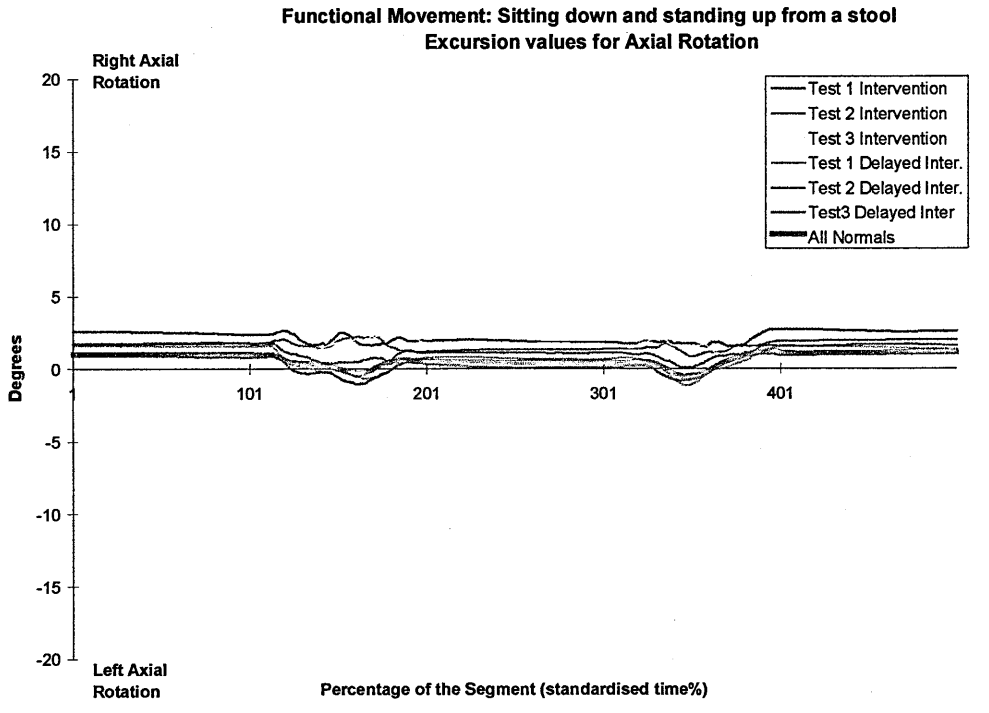


Figure 12.15 Axial Rotation Excursion Values during sitting down and standing up from a stool

A generally smooth pattern, without disruptions, could be observed during sitting down and standing up from a stool in all movements (primary and coupled movements, figures 12.13 to 12.15). However, a noticeable difference in maximal excursion between healthy subjects and patients in the delayed intervention group was apparent (figure 12.14, blue and purple colour coding). The coupled movements of lateral bending and axial rotation were performed in the same way as in the healthy subjects group albeit with some small disruptions. Only minor differences in amplitude were recorded in the coupled movements during "sitting down and standing up from a stool" (figure 12.13 and 12.15). However, on intervention, the intervention group showed a change in flexion excursion of only -0.7 degrees. The delayed intervention group showed a change in flexion excursion of 2.3 degrees (table 12.8). Both changes are small and of little clinical relevance.

Going up and down a step

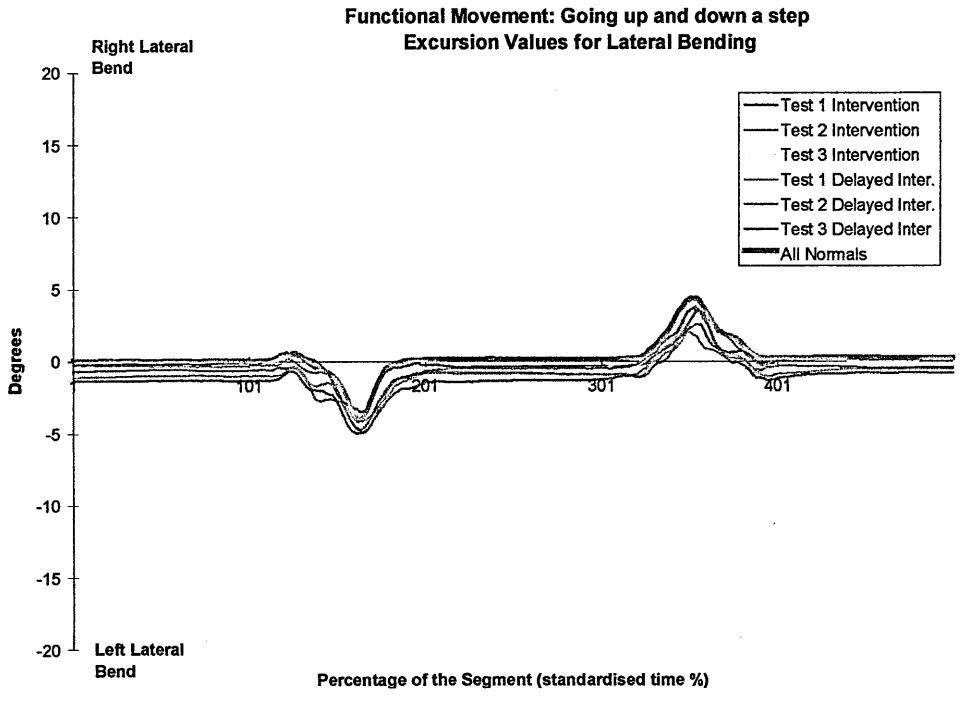


Figure 12.16 Lateral Bending Excursion Values during going up and down a step

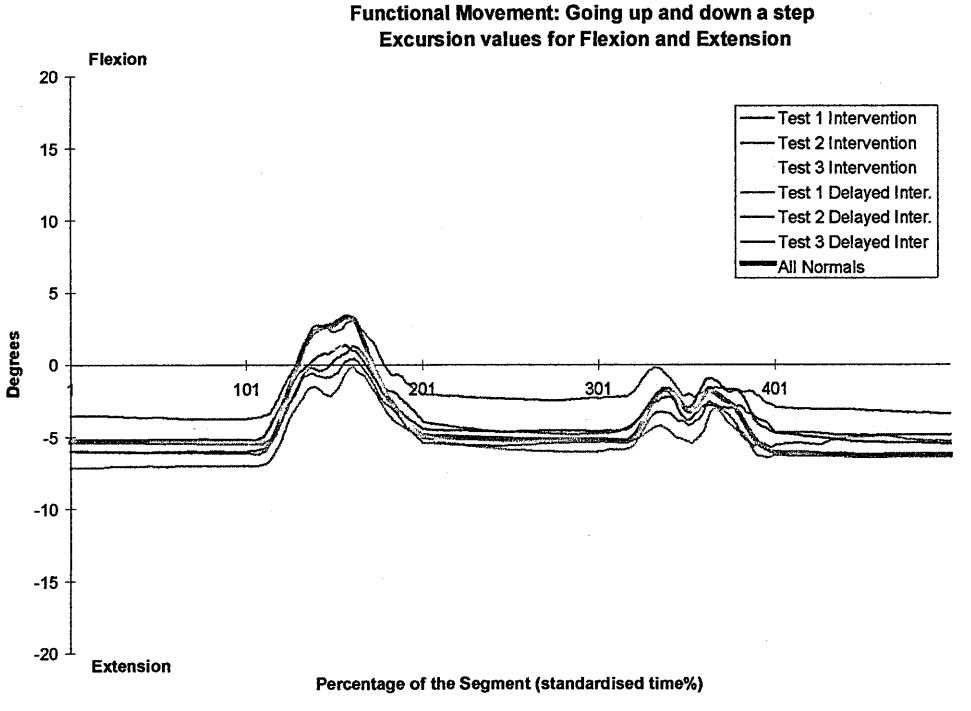


Figure 12.17 Flexion-Excursion Excursion Values during going up and down a step

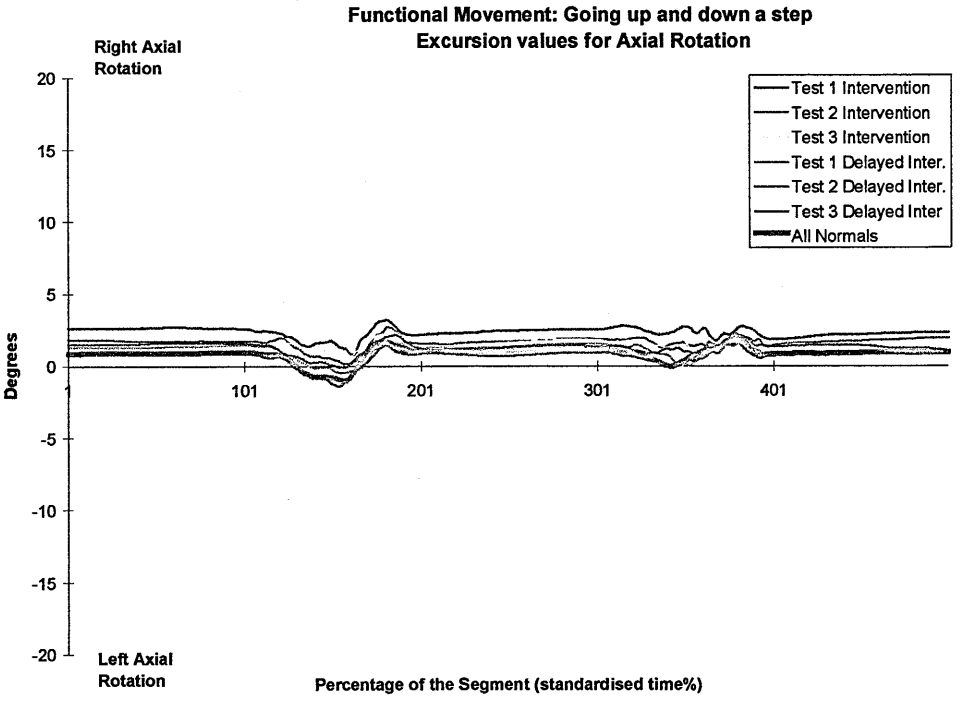


Figure 12.18 Axial Rotation Excursion Values during going up and down a step

The coupled movements during "going up and down a step" (figure 12.16 - 12.18) followed the same pattern in patients and in healthy subjects. Similar to the previous moment, small but noticeable differences in excursion during the primary movement (extension) especially in the delayed intervention group (blue colour coding) were observed. However, only small excursions were required to perform this movement (maximum 8 degrees of flexion).

Picking up a box at the left and putting it down at the right

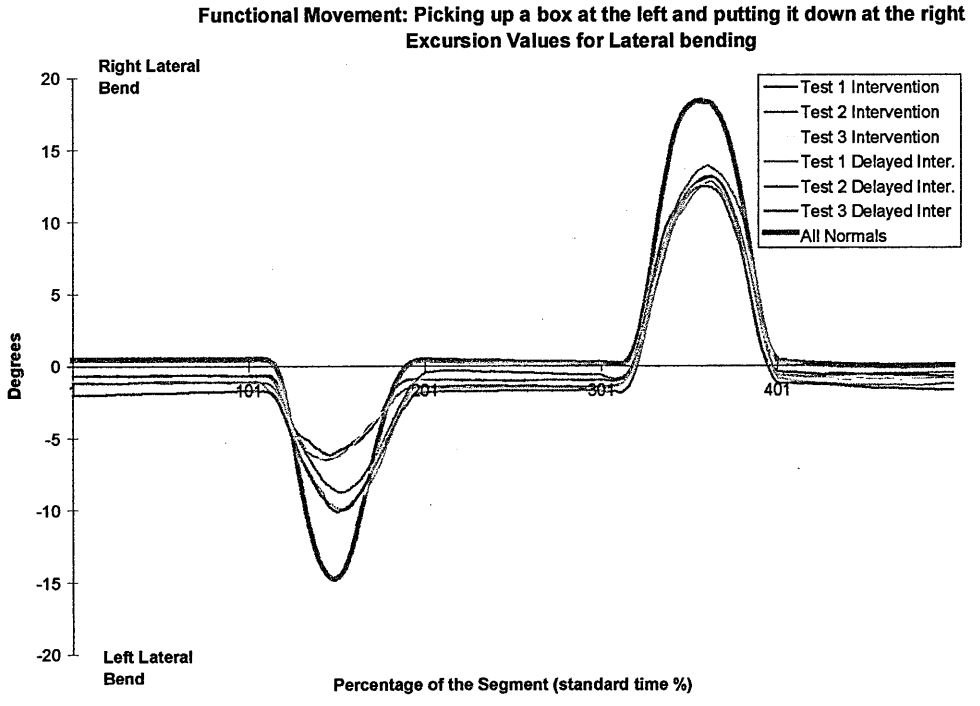


Figure 12.19 Lateral Bending Excursion during picking up a box on the left

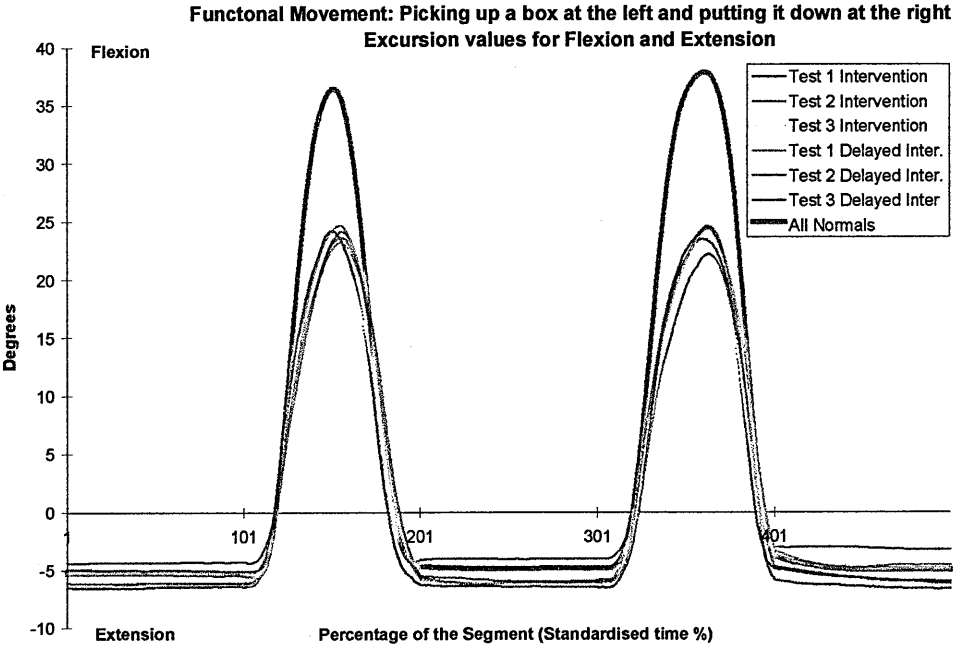


Figure 12.20 Flexion-Extension Excursion during picking up a box on the left

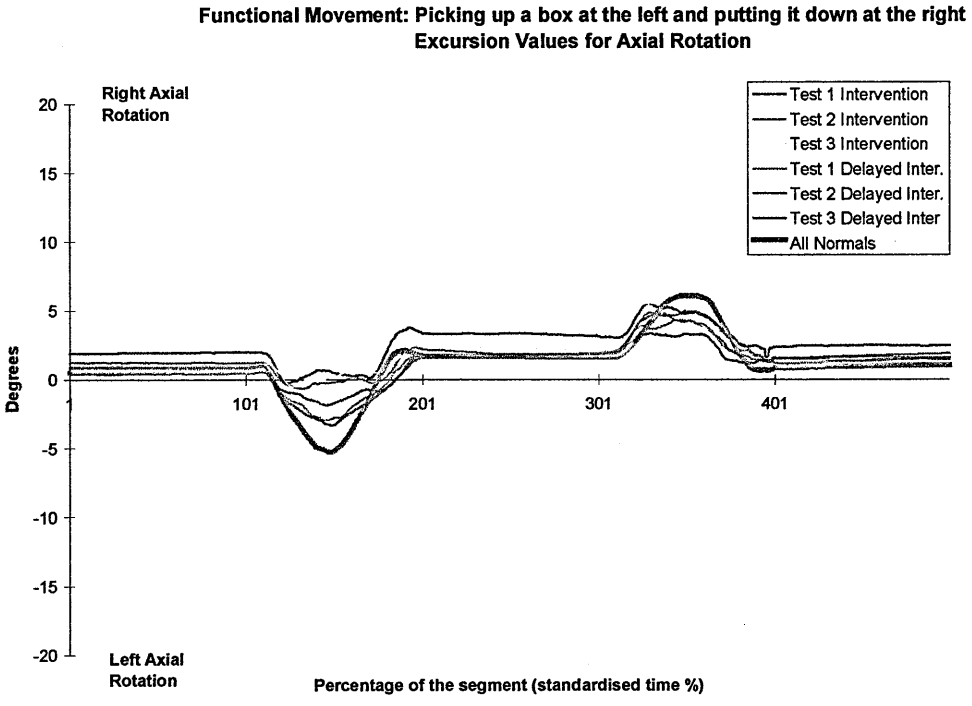


Figure 12.21 Axial Rotation Excursion during picking up a box on the left

Although "picking up a box" (figures 12.19 - 12.21) entails a combination of 2 large movements i.e. flexion and lateral bending, no major disruption in the smooth execution of the movement could be observed. The movements followed the same pattern as displayed by the healthy subjects. There is however, an important difference in excursion values between the patient groups and the healthy subjects. For lateral bending this was 6 degrees, for flexion-extension 10 degrees and for axial rotation 2 degrees.

Picking up a box at the right and putting it down at the left

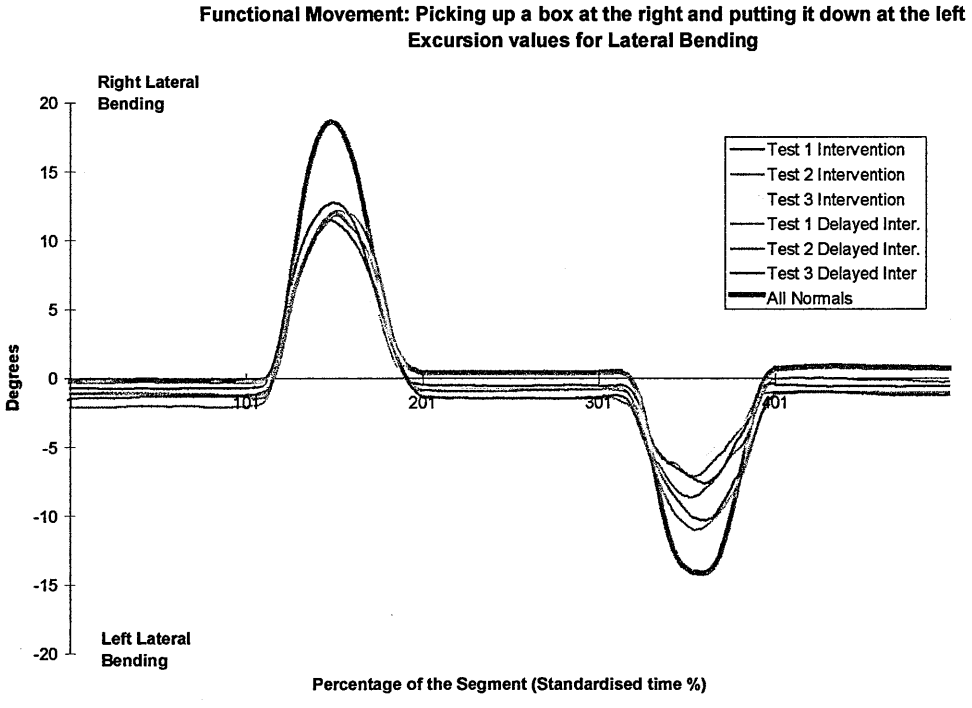


Figure 12.22 Lateral Bending Excursion during picking up a box on the right

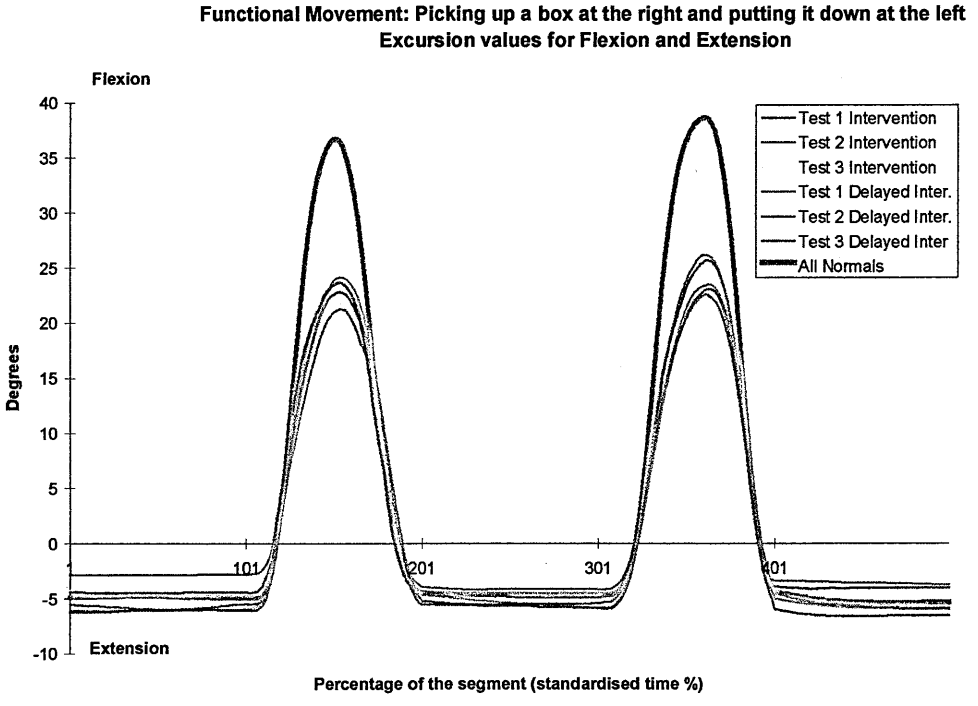


Figure 12.23 Flexion-Extension Excursion during picking up a box on the right

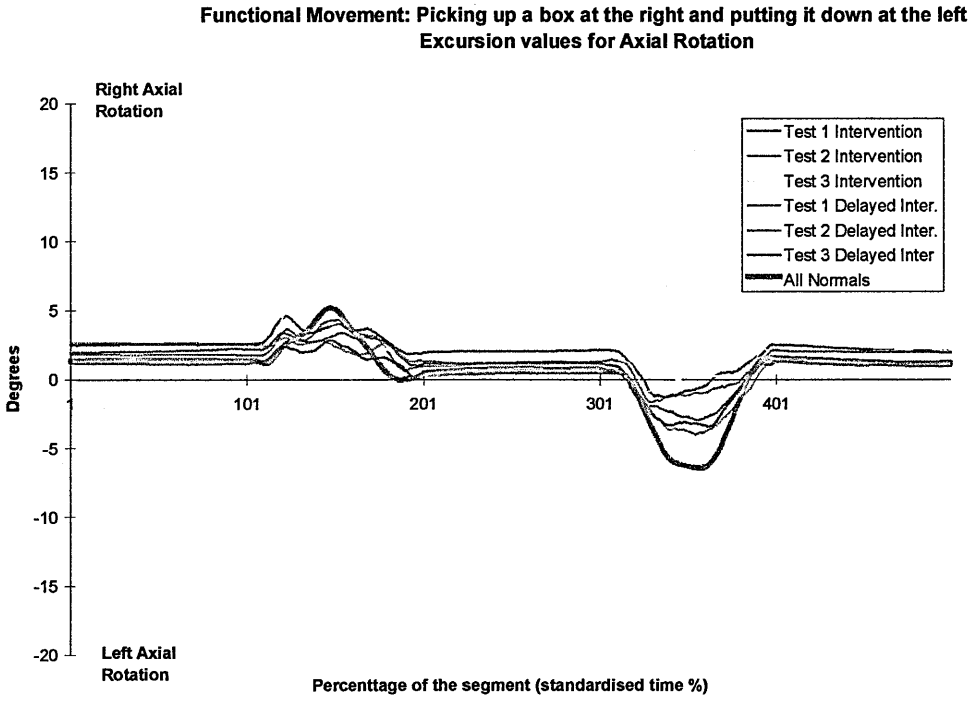


Figure 12.24 Axial Rotation Excursion during picking up a box on the right

Nearly identical patterns, but in mirror image, could be observed during "picking up of a box on the right hand side and putting it down at the left". Again, major differences in the excursion used could be observed between patients and healthy subjects.

Although major differences in the excursions values were observed no trend towards the normal values could be seen from the traces of the intervention and delayed intervention groups.

12.3.2 Excursion Values (functional movements)

Table 12.7 provides a summary of the primary and coupled movements excursion during 4 functional movements and over the 3 different tests. A comparison of all these values with excursion values obtained in healthy subjects is made

Functional Movement			Intervention group n=20			Delayed intervention group n=21			Healthy subjects
	Primary Movement	Coupled Movement	Test One (Degrees)	Test Two (Degrees)	Test Three (Degrees)	Test One (Degrees)	Test Two (Degrees)	Test Three (Degrees)	(Degrees)
Sitting down & standing up		Lateral Bend	8.7	8.6	8.8	8.5	7.7	7.5	5.9
	Flexion		30.6	29.9	28.6	27.9	26.5	28.8	32.9
		Axial Rotation	6.8	6.6	6.3	5.9	5.0	5.3	4.9
Going up & down a step		Lateral Bend.	9.2	9.2	9.4	12.1	11.1	11.3	11.3
	Flexion		10.5	11.9	11.3	11.1	11.5	11.4	13.9
		Axial Rotation	7.3	6.8	6.9	7.1	6.4	6.8	6.7
Pick up box at the left side		Lateral Bend.	22.1	21.7	21.7	26.5	23.8	24.4	35.0
	Flexion		34.8	33.5	31.8	36.1	34.7	36.3	47.3
		Axial Rotation	11.5	11.2	11.2	11.6	11.1	12.7	15.2
Pick up box at the right side		Lateral Bend.	22.3	21.6	21.1	25.6	22.9	24.8	34.5
	Flexion		33.6	33.7	32.9	36.1	33.3	34.9	47.4
		Axial Rotation	10.9	10.9	11.5	11.8	11.2	12.4	15.5

Table 12.7 Excursion values in 4 functional movements and during 3 tests and comparison with excursions obtained by 100 healthy Subjects.

Table 12.7 reveals some interesting differences between the patients groups and the healthy subject group in joint excursion, when performing 4 functional movements. During "sitting down and standing up from a stool" the coupled movements excursions in the patients group exceeded the values of the healthy subjects.

An opposite trend was found in the primary movement of flexion. The differences, however, were small. The same findings could be observed during "going up and down a step" with the primary movement of flexion reduced and the coupled movement of lateral bend increased in the patient group.

The symmetrical movements of "picking up a box at one side and putting it down at the other side", showed substantial decreased values in both primary and coupled movements between the patients and the healthy subjects.

12.3.3 Analysis of the differences between tests in the randomised controlled trial (functional movements)

In order to determine if a statistical analysis was necessary, differences in excursion values during the tests before and after the intervention i.e. between test one and two for the intervention group and between test two and three in the delayed intervention group were calculated.

Table 12.8 provides an overview over the differences in excursion before and after a mobilisation.

	Intervention group (n=20)			**Delayed Intervention group (n=21)**		
Functional Movement	**Lateral bending**	**Flexion extension**	**Axial rotation**	**Lateral bending**	**Flexion extension**	**Axial rotation**
Sitting down and standing up	-0.1	-0.7	-0.2	-0.2	2.3	0.3
Going up and down a step	0	1.4	-0.5	0.2	0.1	0.4
Picking up a box at left side	-0.4	-1.3	-0.3	0.6	1.6	1.6
Picking up a box at right side	-0.7	0.1	0	1.9	1.6	1.2

Table 12.8 Differences in excursion values between tests before and after a mobilisation treatment (all values in degrees) .

From table 12.8 it can be seen that the maximum change obtained for lateral bending was 1.9 degrees with an average change of 0.5 degrees. For flexion-extension a maximum change of 2.3 degrees and an average change of 1.1 degrees was seen and for axial rotation a maximum change of 1.6 degrees and an average change of 0.5 degrees was obtained. These changes are relatively small and of no clinical relevance, therefore a comprehensive statistical analysis was not deemed necessary.

13. Discussion: Lumbar spinal kinematics in healthy subjects

13.1 Introduction

This chapter identifies and discusses several important issues pertaining to the kinematics of the lumbar spine in healthy subjects.

A database for gender and age has been established. The issues revealed by the data analysis which included excursion plots, excursion values and kinematic movement patterns will be discussed in the following sections for 6 gross movements and 4 functional tasks investigated. Furthermore, the validity of the measurement system will be examined by comparing the obtained values to values obtained by other 3 D studies and X-ray data. Finally, the effects of age, gender, height and mass on lumbar kinematics in healthy subjects will be discussed.

When comparing and contrasting the results of this study to others reported in the literature, the discussion will be limited to relevant studies on normal 3 dimensional kinematics of the lumbar spine for the following reasons:

Many authors have attempted to measure gross movements in healthy subjects using a variety of measurement techniques as reviewed in chapter 2 (Measurement of lumbar spinal kinematics). A direct comparison of the excursion values with most of the non-3 dimensional studies, would be inappropriate given their respective limitations, lack of validity and the differences in measurement protocols used. Moreover, several of these measurement devices fail to report values in degrees which makes a direct comparison difficult. Therefore, a comparison with studies reporting 3 dimensional measurements would be more appropriate. This review will take into account the similarities and differences in protocols used and the nature of the measurements systems employed. In particular, three

studies (Buchalter et al, 1986; Hindle et al, 1990 and Russell et al, 1993) reported data recorded by an electro-magnetic measurement device, similar to the one which was used in this study (3 Space Isotrak).

A review of the results of the present study in relation to these three studies will allow the consistency of the 3 Space Isotrak device to be assessed when measuring the gross movements of the normal spine. A further comparison with 3 D studies, using a different technology, will allow the concurrent validity of electromagnetic goniometry to be established.

Values for 3Dimensional Lumbar Spinal Motion measured directly in Degrees (SD)

Study	Device Used	Age Range	Inclusion Criteria	Number of Subjects	Flex. °	Ext. °	Flex &Ext	SBL °	SBR °	SBL& SBR°	AxL °	AxR °	AxL& AxR
Dopf et al 1994	CA-6000 SMA	20-35	No LBP 12mnths. No Back surgery No prior disability because of LBP	120(60F,60M)	81 (10)	34(10)	115(16)	46(7)	45(7)	91(13)	43(7)	42(7)	85(13)
Gomez et al 1991	Isostation B-200	20-50+	No LBP 6 mnths.	168(83F,85M)	61(9)	34(1)	95	37(6)	36(6)	70(12)	36(5)	36(5)	72(10)
Buchalter et al 1986	Isotrak 3Space	20-41	No spinal deformities	60(33F,27M)	56	21	77	23*	23*	47	7	7	15(12)
Hindle et al 1990	Isotrak 3Space	20-50+	No LBP 6 mnths No previous spinal surgery	80(40F,40M)	70	23	93	26*	26*	52	15	15	29
Dvorak et al 1993	CA-6000 SMA	20-70	No LBP 12 mnths	104(42F,62M)	63(4)	24(10)	87(14)	29(7)	30(7)	59(14)	41(9)	41(6)	82(15)
Russell et al 1993	Isotrak 3Space	20-69	No LBP 6mnths No treatment for LBP	200(100F,100M	67(10)	21(7)	88(17)	23	23	47(10)	15	15	31(9)
Esola et al 1996	3DOpto-electronic	23-37	No history of LBP	21(8F,13M)	43(10)								
Petty 1995	CA-6000 SMA	18-23	Asymptomatic for LBP	18F	74	35	109						
Mc Gregor et al 1995	CA-6000 SMA	25-50	No history of LBP	20(12F,8M)	57(11)	20(15)	77(26)	30(11)	30(7)	60(14)	25(7)	24(7)	49(14)
Schuit et al 1997	CA-6000 SMA	20-48	No LBP 6mnths	13(9F,4M)	62	21	83	31	31	62			
Troke et al 1996	CA-6000 SMA	21-35	No history of LBP	11(4F,7M)			90(10)	30	30	61(9)	6	6	12(4)
Mean					**63**	**26**	**91**	**30.5**	**30.5**	**61**	**22**	**23**	**45**
Present study	**Isotrak 3 Space**	**20-60^{+}**	**No treatment 6 mnths**	**100(50F, 50M)**	**55(9)**	**23(10)**	**78**	**22(6)`**	**22(6)**	**44**	**14(5)**	**13(5)**	**27**

Flex.= Flexion, Ext= Extension SBL= Sidebending to the left, SBR= Sidebending to the Right AxL= Axial Rotation to the Left, AxR= Axial Rotation to the Right .

Table 13.1 Values for 3Dimensional Lumbar Spinal Motion measured directly and comparison with present study (red).

Values for 3Dimensional Lumbar Spinal Motion measured by In vivo X-ray (in Degrees)

Study	Device Used	Age Range	Inclusion Criteria	Number of Subjects	Flex °	Ext °	Flex &Ext °	SBL °	SBR °	SBL& SBR°	AxL °	AxR °	AxL& AxR°
Schuit et al 1997	X-ray	20-48	No LBP history	13(9F,4M)	61	20	81	31	32	62			
Dvorak et al 1991	X-ray	22-45	No LBP history	41(18F,23M)			89	29	29	58			
Pearcy et al 1984	X-ray	25-36	No LBP history	11M	51	16	67	17	18	35			
Mean					**56**	**18**	**80**	**26**	**26**	**52**			
Present study	**Isotrak 3 Space**	**20-60^{+}**	**No treatment 6 mnths**	**100(50F, 50M)**	55(9)	23(10)	78	22(6)	22(6)	44	14(5)	13(5)	27

Flex.= Flexion, Ext= Extension

SBL= Sidebending to the left, SBR= Sidebending to the Right

AxL= Axial Rotation to the Left, AxR= Axial Rotation to the Right (all values in degrees).

Table 13.2 Values for 3 Dimensional Lumbar spinal motion measured by In vivo X-ray and comparison with values obtained in the present study (red colour coding).

The study by Buchalter et al (1986) was the first to measure three dimensional lumbar spinal motion In vivo effectively and non-invasively. These researchers used a 3 Space Hybrid System, (Polhemus Navigation, VT, U.S.A) which was a predecessor of the 3 Space Isotrak used in this study. In addition to measuring lumbar spinal motion, cervical and thoracic mobility were recorded, as this device allowed multiple sensors to be used. The device was validated by placing the sensors on a protractor. An accuracy to at least 0.5 degrees in 360 degrees in 2 axes and in 180 degrees in the third axis was reported. These values are similar but better than the values obtained in the present study (0.43 degrees in the flexion range ± 90 degrees). However, in the present study the working range was limited to ± 80 degrees due to the mean systematic error increasing rapidly after 80 degrees. A further decrease of the working range to ± 70 degrees was due to cross talk between the 6 recording channels (chapter 6: Validation). Buchalter et al (1986) reported no limitations on the working range of the device. However, from the maximum excursions reported during patient testing one could conclude that the valid working range was not exceeded in practice. Another important difference in methodology between the two studies was related to the different zeroing procedure used. As described in chapter 8 (Protocol) a novel, reliable alignment technique was developed for the present study. This manual technique, using 2 adjustable wedges, made the zeroing procedure independent of computer control. A prone lying position was used to perform this procedure in order to accommodate LBP-patients and to provide a stable underlying surface. Buchalter et al (1986) did not provide an explanation of how the zeroing procedure was performed. However, it is assumed that this procedure was done under computer control, with the subject standing in a "relaxed erect posture". Finally, Buchalter et al (1986) used a younger population (average age 31.7 y, range 20-41 y) compared to the other studies where an age spectre from young (20) to old (60+) was used.

The studies by Hindle et al (1990) and Russell et al (1993) are very similar in nature. Both using a 3 Space Isotrak to establish a normative database. However, the study of Russell et al (1993) used a larger number of subjects (n=20) when compared to Hindle et al (1990) (n=10) in each age/gender category in order to substantiate or contradict the findings of Hindle et al (1990).

Two major differences could be observed between the present study and the studies by Hindle et al (1990) and Russell et al (1993). First, the lumbar segment covered in the Hindles' et al and Russells' et al studies did not include T12 unlike the present study which included T12. Second, these authors applied a correction factor to the recorded values as they found a systematic error in the accuracy of the measurement device. The correction was applied with the regression equation:

$$Y = 1.056\,X + 0.509$$

Where Y = true angle and X the 3 Space Isotrak reading

This correction factor has the effect of increasing the measured values by 5.6%. In addition, the sample in Hindle et al (1990) did not include an 60-69 age cohort as in Russell et al (1993) and the present study. Finally, Hindle et al and Russell et al mounted the source and sensor of the 3 Space Isotrak directly to the skin with double sided tape. They reported difficulty during testing especially in axial rotation with this attachment method. In contrast, the present study used an indirect method of attachment which remained secure throughout the test period. Adams and Dolan (1995) concluded that the 3 Space Isotrak could give accurate values of lumbar flexion if the device was mounted on the back with the leads running horizontally. If the leads run over the shoulders, flexion movements tend to be exaggerated possibly as a result of the leads tilting the sensor. In the present study, however, particular care was taken to attach the sensor module firmly to the skin overlying T12. The leads, running over the shoulder, were attached to the skin with non-allergenic

tape and some slack in the cables was given so that no noticeable pull on the leads took place. No apparent skin movement could be observed during the measurements. The present study did not therefore encounter the same problems with attachment as those experienced by Hindle et al and Russell et al.

Keeping in mind the above mentioned methodological and protocol differences, these 3 studies will provide a basis for comparison of excursion values and influences of age, gender, height and mass.

In order to discuss the results from the present study the following sequence will be adhered to:

The results obtained in 6 gross movements will be discussed in turn. The excursion plots, excursion values of the coupled movements, excursion values of the primary movement and the influences of age, gender, height and mass on the primary movements will be discussed in separate sections. For the excursion values, where possible, comparison will be made to data from other Isotrak studies, X-ray studies and other 3 dimensional movement analysis studies of gross lumbar movement.

Subsequently the 4 functional movements recorded will be discussed.

This study was the first to assess functional movements and hence for these tests no data is available for comparison from either X-ray or movement analysis studies. The discussion of these tasks is therefore limited to the nature of the excursion plots and excursion values for the coupled and primary movement and appears as one section

13.2 Analysis of 6 gross movements

13.2.1 Forward flexion

(i) Excursion plots

From the mean and individual excursion plots (figure 10.2 and 10.3) it can be observed that both the principal movement (forward flexion) and the coupled movements (lateral bending and axial rotation) were performed in a smooth manner. The subjects moved continuously in the direction of the desired primary movement without notable reversals in direction. No noticeable disruption in the uniform performance of the movement was observed. Furthermore, it can be seen that the subjects started the movement from the standing position i.e. from the flexion angle of -5° of forward flexion or 5° of extension. They then performed forward flexion to a maximum excursion of, on average, 55.4° degrees and returned to a similar standing position after the movement was completed. The standing position of 5° of extension implies that the sensor module was rotated by 5° when moving from prone lying position (the neutral position in which the zeroing procedure was performed) to the erect position. These 5° reflect the average change in lumbar lordosis angle, measured externally by a 3 dimensional electro-magnetic goniometer between prone lying and standing. A similar standing position was observed in all other gross and functional movements examined. Further, all subjects were re-tested in prone lying at the end of each test session and no systematic error in the recorded angle for this neutral position was found. It can thus be concluded that standing up from a prone lying position was accompanied by 5° of sagittal plane rotation. These observations also imply that the device was not displaced by coming from the prone to the erect position and stayed firmly attached throughout the test session.

The consistency in starting and neutral position over the whole movement spectrum indicates that no permanent sensor displacement, due to skin movement or other factors occurred when rising up from the prone lying position to an erect position or during the testing of the subject.

During the performance of forward flexion no appreciable coupled lateral bending or axial rotation was observed for the group as a whole (figure 10.2). Hence, the lines representing the mean lateral bending and axial rotation remained close to zero throughout the graph. Although some individual variations were apparent (figure 10.3) these deviations were to both left and right and of similar magnitude and consequently cancelled each other out. Hence the line representing the mean values of lateral bending and axial rotation remained close to 0 degrees, indicating that on average a pure forward flexion was carried out by the group.

These findings indicate that no "organised coupled motion" occurred for the group as a whole. However, "individual coupled motion" occurred and was equally distributed to left and right. In the text which follows the group's coupled motion will be referred to as "organised coupling" whereas the amount of coupling seen in an individual will be referred to as "individual coupling".

It should be noted that where the group performance indicated no organised coupling it is still possible for the individual excursion values to be non-zero indicating some movement of the spine in directions other than that of the primary movements. These individual excursion values are taken to be positive regardless of the direction of the excursion and hence the average individual excursion can be, and, often is, non-zero even when the mean organised coupling is zero.

(ii) Excursion values

Coupled movements excursion values

The majority of the clinical measuring devices available to the health care clinician limit their measurement range to the sagittal plane e.g. skin distraction techniques, spondylometer, flexicurve etc. As the spine is a 3 dimensional structure, it is imperative that the clinician is able to record information on the 3 dimensional lumbar movement. In other words recording both the primary movement and the coupled movements, provides the necessary information to create a full kinematic pattern of lumbar spinal movement.

In the present study the primary movement of forward flexion was associated with, on average, 5.5 degrees of individual coupled lateral bending and 5.9 degrees of individual axial rotation (table 10.1). However, as mentioned above these coupled movements were equally distributed in both directions and hence cancel each other out. It is thus concluded that no organised coupling occurred when a forward flexion movement was performed but that any individual may display individual coupling of approximately 5 degrees of lateral bending and axial rotation when performing forward flexion.

Although Buchalter et al (1986) did report some motion in the frontal and coronal plane, these were small in amplitude (3 degrees in lateral bending and 1 degree in axial rotation). Buchalter et al (1986) attributed these small variations in coupled movements to the sagittal curve of the spine together with muscular control. Similarly, no out of plane movements during forward flexion in standing were reported in the study by Hindle et al (1990). Russell et al (1993) performed chi-square statistical analysis of lateral bending and axial rotation coupling on flexion in both males and female cohorts and no significant coupling values were reported. Hence all 4 studies agree on the lack of organised coupling during forward flexion.

The large degree of agreement in the results of these 4 studies suggests that, in the normal lumbar spine, the movement of forward flexion is not accompanied by a substantial degree of lateral bending or axial rotation. It is therefore concluded that healthy subjects are able to produce pure forward flexion.

Primary movement excursion values

This study indicates that, in the healthy lumbar spine, an excursion value of approximately 55.4 degrees of forward flexion can be expected.

The mean excursion values for forward flexion reported by Hindle et al (1990), (67.2 degrees) and Russell et al (1993), (70.2 degrees) markedly exceeded the values reported in Buchalter et al (1986)s (56 degrees) and the present study (55.4 degrees) (table 13.1).

Four possible reasons for these differences could be put forward:

- The application of a correction factor by Hindle et al (1990) and Russell et al (1993) inflated the true values recorded by 5.6% or approximately 4 degrees.
- Hindle et al (1990) and Russell et al (1993) mounted the 3 Space Isotrak directly to the skin with double sided tape rather than using specially designed base plates and wedges as in the present study.
- They reported difficulties with the attachment and speculated that skin movement causing the sensor to move relative to the underlying vertebrae was the main reason for the overestimation of the excursion values relative to X-ray. No permanent movement of the source and sensor was observed in the present study.
- Finally, they excluded the motion segment between L1 and T12. Given that the thoracic spine curves in the opposite direction to that of the lumbar spine this may also have lead to increased values in their study compared to the present and X-ray studies.

The average flexion value reported in Hindles' et al (1990) and Russells' et al (1993) work was 68.7 degrees. This was well in excess of the average values recorded by X-ray (56 degrees, Table 13.2). These authors concluded that movement of the sensor in a cranial direction was probably the mean reason for this overestimation of the true excursion value. However, approximately 4 degrees of the error can be attributed to the unjustified re-calibration of the device and the resulting 5.6% inflation of their results. Because Hindle et al (1990) were aware that there was an overestimation of the true excursion values for forward flexion they concluded that "the system is likely to be primarily of use when monitoring relative changes in spinal motion in an individual" e.g. when assessing changes in excursion values before and after a mobilisation treatment in the same patient.

It is gratifying that the results from the present study represent most closely the values obtained by X-ray measurements (table 13.2). This despite the use of different subjects in each study. Furthermore, when the results of the present study are compared to the mean results of the three X-ray studies of lumbar spinal motion found in the literature (table 13.2) it can be seen that the present study is in excellent agreement (55 degrees) with the mean X-ray data by Schuit et al (1997), Dvorak et al (1991) and Pearcy et al (1984) (56 degrees). Furthermore, when comparing the present study to all motion analysis studies using different 3 D-systems to measure lumbar flexion, it can be seen that the two 3 Space Isotrak studies in which the device was attached carefully, the wires controlled and no correction factor applied, show the highest agreement with X-ray data and give values to within 1 degree of the mean X-ray value.

The results of the present study for flexion would seem to have external validity. They do not concur with Hindle et al (1990)'s conclusion that the device be limited to " monitoring

relative change in individuals " but, in contrast, support the conclusion that the absolute values have validity. The 4 studies using the CA-6000 (Petty, 1995; McGregor et al, 1995; Schuit et al, 1997 and Troke et al, 1996) give a mean value of 64 degrees while the study using the Isostation B-200 (Gomez et al, 1991) indicates 61 degrees and the only study included using an opto-electronic device (Esola et al, 1996) reported a mean of 43 degrees. It should be noted that for all these studies the age range is less than in the current study and limited to the categories of young healthy subjects. However, the results of this study indicate that for the youngest subjects a mean flexion of on average 57.2 degrees (table 10.15) can be expected. It would seem that the 3 Space Isotrak system, as implemented in this study and in the study by Buchalter et al (1986), show the best correlation with the limited X-ray data available for forward flexion. Moreover, the 3 Space Isotrak would appear capable of picking up small changes in excursion in the main and coupled movements

It can thus be concluded that the 3 Space Isotrak and the newly developed attachment method, used in the present study, gives an excellent indication of the actual movement of the lumbar spine in forward flexion.

(iii) Effects of age, gender, height and mass on lumbar mobility

The results of the regression analysis (table 10.3) suggest that age has a significant influence on forward flexion mobility. In contrast, gender, height and mass were not significantly related to forward flexion. The regression equation allowed some predictions to be made i.e. using the regression equation one could predict subjects normal flexion mobility, given the persons age. Further, the regression indicates that the normal human spines loses 1.18 degrees of flexion per decade of life following adulthood.

A general decrease, with age, was recorded over the whole age spectre (table 10.15), except for the male 50-59 age cohort where some high excursion values were observed. Examining the median for the 50-59 males cohort (table 10.15) indicates that 50 % of the males in this age group had an excursion of 58.2 degrees. This was higher than the values obtained by the 20-29 year olds. The reason for this unexpected result, in this age group, could be attributed to a genuine higher performance of the entire group (10 subjects) or to change due to sampling. The fact that the excursion values for the 50-59 group are higher than the values in the other age cohort suggest that these values, when used as normative data, have to be interpreted with caution. However, despite the increase in mean flexion value in the male 50-59 age cohort a significant decrease ($p=0.022$) between the younger (20-29) and the older (60^{+}) age group was seen (table 10.12), confirming the general linear trend of decreasing forward flexion mobility with age.

Buchalter et al (1986) indicated approximately 10 degrees of decrease in flexion between younger (21-30 y) and older (31-40 y) age groups. Also, a statistically significant inverse relationship between age and sagittal motion ($r = -0.27$, $p=0.02$) was reported. The present study and the study by Buchalter et al (1986) are in agreement regarding a significant inverse linear relationship between age and flexion, but not on the amount of change per decade.

In contrast, Hindle et al (1990) reported an increase in forward flexion with age. However, this trend was observed in the female cohort only. These authors suggested that the increase in forward flexion in females could be attributed to an increased lumbar lordosis with age. No references to substantiate this claim were given. Carr et al (1991) as cited by Russell et al (1993) showed no difference in the degree of lumbar lordosis in the older female child i.e.

14-16 years and female adult groups investigated. Carr's study therefore suggested that there is no overall change in adult lumbar lordosis with age. Nevertheless, Russell et al (1993) suggested that individual lordotic angles could change due to postural changes, mass gain or loss. Also wearing of high heels could result in hyperlordosis due to altered pelvic inclination as reported by Opila et al, 1988.

Russell et al (1993) reported a significant ($p<0.05$) decrease in flexion mobility between younger and older age cohorts, which concurs with this study and that by Buchalter et al (1986). Interestingly, Russell et al (1993) reported a significantly higher degree of mobility (no p-value reported) in the 30-39 female cohort compared to the 20-29 female cohort. No reason for this was given. In general, 3 of the 4 studies agree that there is a decrease in forward flexion with age and the present study indicates this to be of the order of 1.18 degrees per decade (table 10.3).

In the present study females displayed in general, higher mean values then their male counterparts except for the 50-59 & 60+ age cohorts (table 10.15). However, hypothesis testing using a 2-tailed t-test for independent samples at a 95% confidence level could not find a significant difference ($p>0.05$). Moreover, single regression analysis could not find significant influences of gender on forward flexion ($p=0.684$). Buchalter et al (1986) et al reported that there was no linear relationship between flexion and gender. In contrast, Hindle et al (1990) showed males having significantly more flexion than females ($p=0.025$). Although the flexion values increased in the older female cohorts, on average they remained lower than in males. Hindle et al (1990) further pointed out that his study was relatively small (consisting of 80 subjects with 10 subjects in each cohort) and an attempt to allow for factors such as height and mass would have been inappropriate in groups of only ten subjects. Finally, Russell et al (1993) reported a higher sagittal mobility for males in the 20-

29 and 40-49 age group but no significant differences (no p-value reported) in the other age groups. The 4 studies are therefore in agreement in finding no significant differences with gender.

Summary for the gross movement of forward flexion

In summary then, the results of the present study for forward flexion show a high degree of agreement with those of Buchalter et al (1986) and the X-ray studies. These studies agree that on average 56 degrees of forward flexion can be expected from the normal lumbar spine. It would also appear that age reduces the amount of forward flexion available but further work is required to confirm the degree of loss suffered per decade. Gender would appear to be a less significant factor but there is some evidence to suggest that females are more flexible than males. Finally, it can be concluded that the forward flexion motion is smooth and direct and, in general, is conducted in a pure fashion without significant organised coupled motion.

13.2.2 Extension

(i) Excursion plots

From the mean and individual excursion plots in figures 10.4 and 10.5 it can be seen that, again, no disruptions in the smooth execution of the movement occurred. As for the test of forward flexion, a standing position for the extension test of -5 degrees was recorded. A small deviation towards the right could be observed in the mean coupled movement of axial rotation indicating some organised coupling. This would imply that the majority of the subjects rotated slightly to the right when performing the movement of extension. The possible reason for this could be that most of the subjects tended to look over their right

shoulder when performing the movement, which in the majority of subjects is likely to be the dominant. The relevance of this observation however, is limited as the angular change was small (2 degrees). The kinematic pattern observed was similar to that shown in the plots reported by Hindle et al (1990). However, in a study by Pearcy and Hindle (1989), where the repeatability of the 3 Space Isotrak measurements was investigated, no noticeable coupling could be observed from the extension plots displayed. It can be concluded that the normal human spine is able to produce almost pure extension with perhaps a small degree of organised coupled axial rotation to the right.

(ii) Excursion values

Coupled movements excursion values

In the present study a mean individual coupling of 3 degrees in lateral bending and 3.6 degrees in axial rotation was recorded (table 10.1). The majority of subjects performed axial rotation to the right as was shown from the plots. However, the small recorded excursion values suggest that only minor organised coupling occurred during extension.

Buchalter et al (1986) also reported small changes in the coupled movements of axial rotation approximately 3 degrees and lateral bending approximately 1 degree. Buchalter et al (1986) concluded that:

> "as expected, most of the motion occurred in the sagittal plane with no substantial coupling apparent ".

Similarly, Hindle et al (1990) did not report any out of plane movements accompanying extension. Russell et al (1993) reported no overall value but did report separate values for male and female groups. These authors concluded that in general, male and female results were consistent with no significant coupling occurring. The only exception to this was in the

male group where a strong coupling of right axial rotation on extension was shown. No obvious reason for this inconsistency was given.

In general, extension would appear to be performed in a pure fashion without substantial bending or rotation.

It is interesting to see that in the present study the majority of subjects performed small right axial, individual coupled movements Buchalter et al (1986) also reported larger axial rotations than lateral bend values and Russell et al (1993) found small but significant coupling in axial rotation in males. It appears therefore that where small individual coupled movements occur, these are primarily related to the coronal plane and not to bending in the frontal plane. Furthermore, these individual coupled movements occur more commonly to the right than to the left and lead to a small degree of organised coupled axial rotation to the right. However, the amplitude of these coupled movements, approximately 2 degrees, is of questionable clinical relevance.

The broad consistency in results within the 4 studies is similar to the results reported for the other movement in the sagittal plane i.e. forward flexion. These findings suggest that lumbar sagittal motion, within the physiological range, occurs without substantial coupling in lateral bending or axial rotation.

Primary movement excursion values

The present study indicates that in the living healthy lumbar spine an excursion value of 23.2 degrees of extension can be expected. Buchalter et al (1986) reported a mean excursion

value of 22 degrees while Hindle et al (1990) and Russell et al (1993) reported values of 22.8 and 21. respectively (table 13.1).

In contrast to forward flexion, no major discrepancies in excursions between the studies were reported.

Also for extension the consensus is that the 3 Space Isotrak system records excursions in excess of that reported in X-ray studies (table 13.2) by approximately 5 degrees. Russell et al (1993) explained this primarily due to skin movement causing the sensor to move relative to the underlying vertebrae. However, the reported values in all 4 studies were similar despite different forms of attachment. Comparing the 3 Space Isotrak average extension value (22 degrees) to the values obtained in studies where a CA-6000 device was used (21, 20, 35, 24, 34 degrees) in three of the five studies good agreement was observed. However, in two studies, values 12 degrees in excess of the current study and double the given X-ray mean value (18 degrees) were apparent. Both these studies are on a young age group (18-23 and 20-35) and involve female subjects (100% female, Dopf et al 1994 and 50 % female, Petty et al, 1995). In the present study significant increases in extension were found in the young and female categories of the order of 3 degrees per decade for age and 7 degrees for gender. Hence the higher values in these studies may be due to the difference in sample population. Gomez et al (1991), using an Isostation B-200, also reported data double the X-ray value but had a mix of gender and ages and hence the difference can not be attributed to the sample

It can be questioned if X-ray should be considered as "gold standards" for evaluating extension values given the difficulties of 3-D modelling (surface detection) and of fitting a co-ordinate system to such models (Allard et al, 1995). In extension the lumbar spinal processes are in close packed arrangement and difficult to visualise by X-ray. At present

further work is required to explain the difference in findings between the X-ray studies, 3 Space Isotrak values and the results of the other methods. However, of all the motion analysis methods used to measure the extension of the lumbar spine, the 3 Space Isotrak system would appear the most consistent and to give values which best approximate X-ray data.

(iii) Effect of age, gender, height and mass on lumbar extension mobility

In the present study a gradual decrease in lumbar extension mobility, with age, was seen over the whole age spectre. The results of the regression analysis (table 10.4) confirmed this trend and indicated that age, gender and mass were all significantly related to extension mobility.

For age a significant ($p<0.001$) decrease in extension, equivalent to a loss of 3.15 degrees per decade was found. Similarly, Buchalter et al (1986) reported a weak statistically significant inverse linear relationship between age and sagittal plane movement ($r = -0.27$, $p<0.02$). These authors considered sagittal plane movement, and not forward flexion and extension as separate movements. Hence the same correlation coefficient is reported for forward flexion and extension. Hindle et al (1990) showed a general trend for decreasing extension mobility with advancing age. An ANOVA-design was used to test for significant differences in ranges of motion between age groups. The results suggested extension to be significantly reduced with age ($p< 0.05$). Furthermore, testing for correlation between age and the range of movement revealed a weak significant correlation (no value reported). However, this trend appeared to be inconsistent. For instance, the males > 50 age group displayed higher average values than the 30-39 age group. Similarly, the over 50 female group having higher excursions then the females 40-49 group. It was therefore concluded that only a general trend for decreasing movement with advancing age was shown. Russell

et al (1993) reported a consistent decrease in extension mobility over age in the male cohort. In the female cohort decreasing values were reported in the younger age category whereas identical mean excursion values were reported for the 3 oldest age groups. Significant differences between young (20-39) and old (50-69) groups were reported in the male and the female groups.

In summary, a broad agreement exists on a decrease of extension flexibility throughout the age ranges and the present study indicates the decrease to be approximately 3 degrees per decade (table 10.7).

In the present study females showed significantly greater mobility in extension ($p<0.001$) equivalent to a mean difference of 6.8 degrees. Buchalter et al (1986) reported a slightly higher value for females than males but indicated that no relationship between ranges of motion and gender could be seen. Hindle et al (1990) reported no significant difference between males and females. However, the mean values reported suggested that females had larger extension excursions than males. Russell et al (1993) also reported a higher mean value in females (22.4 degrees versus 19.8 degrees in males) but this was only significantly higher ($p<0.05$)-in the 60-69 age cohort. There is good evidence to suggest a difference between males and females exists, with the present study indicating females generating extension approximately 7 degrees in excess of their male counterparts (table 10.16).

The present study found also mass to be significantly ($p<0.001$) related to extension mobility with each extra 10 kilos causing a reduction in extension of 2 degrees (table 10.4). Russell et al (1993) suggested that, in general, people who were heavier could be expected to have greater skin movement which would affect the readings obtained by causing the sensor to move a greater distance relative to the underlying vertebra. This suggestion was

not specifically related to the extension movement but applied to movement in general. Yet, Russell et al (1993) reported no significant correlation between mass and range of movement. A possible reason for the influence of mass on extension mobility but not on flexion although both movements take place in the sagittal plane, might be that when extending, the skin and adipose tissue have a tendency to bunch up thus possibly limiting the movement.

In summary, broad agreement exists on the influence of age and gender to be related to extension mobility with a general decrease in mobility with age and females showing more mobility than males. In addition, the present study indicated mass to be related to extension mobility.

Conclusion for the gross movement of extension

The results of the present study for the gross movement of extension show a high degree of agreement with the studies by Buchalter et al (1986);. Hindle et al (1990) and Russell et al (1993). These studies agree that, on average, 22 degrees of extension can be expected from the healthy lumbar spine. A general consensus exist that 3 D spinal motion records values in excess of that what is reported in X-ray studies. It would appear that age, gender and mass all play a role in reducing extension but further work is required to confirm the degree of loss suffered.

Finally, it can be concluded that the gross movement of extension is performed smoothly and without significant organised coupled motion.

13.2.3 Lateral Bending

(i) Excursion plots

No substantial differences were apparent in the plots of lateral bending to the left and the right (figures 10.6 to 10.9). Therefore, these movements will be discussed under the same heading.

Lateral bending was also carried out in a smooth and continuous fashion. However, unlike flexion and extension, lateral bending was associated with considerable organised coupled forward flexion (12 degrees) when bending to the left (figure 10.6) and to the right (figure 10.8). This was unexpected as the instructions to the subject were designed to produce movement in the frontal plane only. Clear instructions to this effect were given i.e. "glide down with your hand over your knee, without bending forwards or backwards. Keep looking forward while bending to the side "A possible reason for this coupling to occur would be the orientation of the zygapohyseal joints in the lumbar spine. These joints are oriented oblique to the vertical in the lumbar spine and therefore restricting large degrees of axial rotation and sidebending. By virtue of their oblique orientation these joints force the lumbal spine into forward or backward flexion during side bending. No organised axial rotation was found in the present study.

A standing position of 5 degrees of extension and close to 0 degrees in lateral bend and axial rotation was as in forward flexion and extension again apparent before and after the movement.

Buchalter et al (1986) did not present plots of these movements. However, from the histograms presented some coupled flexion (approximately 4 degrees) and axial rotation

(approximately 2 degrees) could be noticed. From the plots presented in Hindle et al (1990)s study, opposite axial rotation and forward flexion was seen to accompany lateral bending to both sides. Russell et al (1993) did not present any plots but indicated a strong coupling of both axial rotation and flexion on lateral bend.

In summary all 4 studies agree on lateral bending being coupled with some degree of forward flexion. In contrast to the studies by Hindle et al (1990) and Russell et al (1993), no organised coupled axial rotation was seen in the present study. No obvious reason as to why axial rotation coupling was present in these two studies could be found. However, although the general protocol for performing sidebending would appear to be the same in the 4 studies, the verbal instructions might have been different causing the subject to perform the movement differently. Also Hindle et al (1990) and Russell et al (1993) mounted the source and the sensor directly to the skin and reported difficulty with this attachment method. It may be that the axial rotation they recorded was an artefact of their poor attachment method.

(ii) Excursion values

Coupled movement excursion values

From table 10.1 it can be seen that lateral bending, on average, is coupled to 12 degrees of flexion and 4.8 degrees of axial rotation in individuals. Given that the mean traces (figures 10.6 and 10.8) show no consistent axial rotation it can be concluded that axial rotation was equally distributed to the left and right.

Buchalter et al (1986) indicated approximately 4 degrees of coupled forward flexion and approximately 2 degrees of axial rotation and concluded that

"some degree of coupling may be occurring, but more likely it is the sagittal curve of he spine together with muscular control that affects these motion".

Hindle et al (1990) reported chi-squared statistical testing suggesting a strong coupling of opposite axial rotation on lateral bend. A strong coupling of flexion occurring with lateral bend was also shown. Russell et al (1993) reported significant coupling ($p<0.001$) of both flexion and axial rotation on lateral bending in males and females.

Agreement would appear to exist that when individuals perform lateral bending some flexion and axial rotation occurs. The present study and that by Buchalter et al (1986) indicate that while flexion occurs consistently (12 degrees), axial rotation appears to occur to either the left (4.8 degrees) or the right (4.8 degrees) hence no overall pattern is observed. In contrast, Hindle (1990) and Russell (1993) found that individual axial rotation produced an overall axial rotation to the opposite side but were in agreement for flexion.

As discussed previously, this could be related to the instructions given to the person on how to perform the movement or might be attributed to the different kind of attachment system used.

Primary movement excursion values

In the present study an average excursion value of 21.7 degrees to the left and 22.9 degrees to the right was obtained. Buchalter et al (1986) Hindle et al (1990) and Russell et al (1993) reported 23, 26 and 23 degrees left and right respectively (table 13.1). Close agreement in reported excursion values is apparent. However, when the mean value obtained in 3 Space Isotrak (24 degrees) studies are compared with other studies using a CA 6000 (33 degrees) (Dvorak et al, 1993; Dopf et al, 1994; McGregor et al, 1995; Troke et al, 1996 and Schuit et al, 1997) or an Isostation (36 degrees) (Gomez et al, 1991) a discrepancy is apparent. The main value obtained by electromagnetic devices is closest to the mean value obtained

by X-ray (26 degrees) (Schuit et al, 1997; Dvorak et al, 1991 and Pearcy et al, 1984) and shows a high level of agreement (difference of 2 degrees)

In summary, although a discrepancy in lateral bending excursion values is apparent when comparing studies using 3 Space Isotrak devices and studies using other 3 D devices it can be seen that the 3 Space Isotrak studies reported similar values to X-ray data. It is therefore concluded that the 3 Space Isotrak system gives the best representation of the actual movement of the lumbar spine in lateral bending.

(iii) Effects of age, gender, height and mass on lateral bending

Age appeared to be significantly related to lateral mobility. Linear regression indicated a loss of 1.8 degrees of sidebending per decade for both the left and right sides (table 10.7). The results of the linear regression analysis were confirmed by statistical testing for the differences between younger (20-29) and older (60+) age groups (Y>O, p=0.000) (table 10.12). Hindle et al (1990) reported a consistent decrease in lateral bending mobility with age in all age groups. An ANOVA-design was used to test for significant differences in ranges of motion between age groups. This analysis confirmed that the trend displayed in lateral bending was, indeed, significant ($p<0.025$).

Russell et al (1993) reported that females 20-39, and 50-69, males 40-49 and 60-69 and males 20-39 and 40–69 all showed significant differences between the young and older groups. These authors concluded that significant movement changes occurred for males and females related to age with the young more mobile than the old. There is therefore agreement that lateral bending is reduced by increasing age and the present study indicates a loss of 1.8 degrees per decade.

No significant relationship with gender was found in the present study (table 10.10). Similarly, Buchalter et al (1986) et al were unable to report a linear relation between RoM and gender. Hindle et al (1990) et al reported slightly higher average excursion values for females (27 degrees) then men (24.2 degrees). This difference, however, was not significant ($p<0.025$).

Russell et al (1993) reported significant differences ($p<0.05$) using a t-test between sexes in the 30-39, 40-49 and 50 -59 age group with females having an higher mobility then men. There is general agreement that gender does not produce significant differences in lateral bending mobility.

The present study suggests also a significant relation of mass and lateral bending mobility to right and left. None of the other studies reported mass as a factor in lateral bending mobility. Bunching up of the skin and adipose tissue are likely to be the causal factor for this restriction which is equivalent to 1 degree per 10 kilograms of mass.

Summary and Conclusion for the gross movement of lateral bending

Close agreement between the present study and other studies using electromagnetic devices exists. The studies agree that, on average, 24 degrees of lateral bending to either side can be expected from the healthy human spine. This mean value is in close agreement with the mean values obtained during X-ray studies. It would also appear that age reduces the amount of lateral bending available but further work is required to confirm the degree of loss suffered per decade. The present study indicates a loss of 1.8 degrees of lateral bending per decade. Gender and mass would appear to be less significant factors but there is some evidence to suggest that females are able to bend further in the frontal plane than their male counterparts.

Finally, it can be concluded that lateral bending is associated with a degree of organised forward flexion.

13.2.4 Axial rotation

(i) Excursion plots

From figures 10.10 and 10.11 it can be seen that axial rotation to the left was coupled with organised extension. This trend however, was not apparent in axial rotation to the right (figure 10.12) where the average value remained close to 7 degrees of extension throughout the movement indicating no organised coupling with extension.

Observing the individual traces (figure 10.13) it becomes apparent that one subject presented with a lumbar lordosis of approximately 40 degrees as opposed to the normal 5 degrees and performed the movement coupled to 20 degrees of forward flexion as opposed to the normal 7 degrees of extension. The average trace for the group will have been affected by this outlier by approximately 0.2 0f a degree which is less than the coupling seen on the left side. The presence of this outlier cannot therefore account for the differences seen in the mean trace to left and right. It might be that organised coupling occurs to the left but not to the right but this requires further investigation. However, if organised coupling does exist it is of a small magnitude for axial rotation. Hindle et al (1989) displayed lateral bending coupling but no consistent coupling of flexion or extension. A similar conclusion to the present study. Buchalter et al (1986) and Russell et al (1993) did not present plots of axial rotation.

(ii) Excursion Values

Coupled Movements

In the present study individuals displayed a mean value of 7.3 degrees of extension and 4.8 degrees of lateral bending (table 10.1) during left or right axial rotation. The lateral bending produced was in general equal to the left and right and hence no overall trend occurred. However, consistent extension was recorded.

Buchalter et al (1986) reported no organised coupling in axial rotation. Hindle et al (1990) indicated strong coupling of opposite lateral bend on axial rotation No significant coupling was seen between axial rotation and any sagittal plane movement.

Russell et al (1993) found a significant coupling of lateral bending on right and left axial rotation in all age groups and of flexion on left axial rotation. Flexion was significantly coupled to right axial rotation in the female cohort only. Broad agreement exists between this study and the 3 other studies in suggesting that when healthy subjects perform axial rotation to the left or to the right some coupled movement occurs. However, discrepancy remains over which coupled movement is most strongly related to axial rotation. Sagittal plane coupling was prevalent in the present study while lateral bend to the opposite side was shown in Hindle et al (1990) s' study. Russell et al (1993) reported coupling in both a frontal and sagittal plane. As with the other gross movements, the amount of organised and individual coupling seen was small.

Primary movement

In the present study 14.0 degrees of axial rotation to the left and 13.5 degrees of axial rotation to the right were found. Buchalter et al (1986) indicated "minimal axial rotation occurring in the lumbar spine and maximal rotation occurring in the cervical spine". From

the histograms presented by Buchalter et al (1986) approximately 7 degrees of axial rotation could be observed. Hindle et al (1990) and Russell et al (1993) reported 14.4 and 15.3 degrees respectively.

Close agreement between 3 of the 4 studies was apparent. Buchalter et al (1986) reported values half of what was found in the 3 others studies. It has to be noted that Buchalter et al (1986) used multiple sensors during their study and therefore compared the relative importance of axial rotation at three different levels i.e. the cervical, thoracic and lumbar spine.

No X-ray studies, reporting axial rotation movements were found but it is known that axial rotation is notoriously difficult to interpret on X-ray due to shadowing and out of plane effects occurring (Allard et al, 1995).

A comparison (table 13.1) with the mean value reported by studies using the CA 6000 (mean 23 degrees, range 6-43 degrees), the Isostation B-2000 (36 degrees) and studies using the 3 Space Isotrak (mean 13, range 7-14 degrees) reveals a substantial discrepancy. The reason for the differences could be the different methodologies and protocols used in these studies. However, axial rotation is known to be severely restricted in the lumbar spine due to the orientation of the zygapophyseal joint surfaces (Adams and Dolan, 1995) Moreover, these authors indicated a maximum axial rotation in the lumbar spine of 3 degrees per lumbar segment measured in cadaver specimens. It is therefore unlikely that rotation values in excess of 18 degrees could be recorded for the 6 motion segments involved in the lumbar spine.

This dissertation casts doubt on the validity of the higher values recorded in some studies. While further work is required to confirm the excursion in axial rotation of the lumbar spine, the values indicated by the 3 Space Isotrak would appear to represent the best estimate of the true value at present both in terms of consistency and absolute value.

(iii) Effects of age, gender, height and mass on axial rotation

Age was significantly related to axial rotation to the left but not to axial rotation to the right. The reason why this occurred is probably related to the inconsistent trend in age related movements (table 10.20) in the male cohort. It can be seen that the 30-39 year male cohort had a substantial reduction in movement whereas the 60+ old male cohort displayed the highest values reported (14.7 degrees). Normative values based on 10 subjects are prone to variations in the mean values recorded, with extreme values having a greater effect. The values for axial rotation to the left (table 10.19), however are more consistent. A gradually decrease in all age groups is seen here for both males and females. The reduction in mobility with age showed to be significant for left axial rotation but not of axial rotation to the right (table 10.12). The reduction in axial rotation with age was extremely small with the data from the present study indicating a loss of approximately 0.5 of a degree per decade in axial rotation. It is likely that small group sizes and a weak trend with age have led to the discrepancy in findings between left and right sides

Although Buchalter et al (1986) reported an inverse linear relationship for age in the sagittal and frontal planes, non-significant correlations were found for horizontal plane movements. Hindle et al (1990) reported no significant age differences in axial rotation. Russell et al (1993) found significant differences between the 20-29 and the age groups 40-49, in the male cohort (young> old) and 30-39 and 60-69, in the female cohort (old>young). Russell et al (1993) concluded that large variation within groups were observed so that a more mobile person in their sixties could have as great a range of movement than a person in their twenties. Russell et al (1993) therefore questioned the usefulness of lumbar spinal normative databases. Based on the results of these 4 studies there is some evidence to suggest that a

small decrease in axial rotation with age of approximately 0.5 of a degree per decade can be expected in the healthy spine.

Significance testing for gender differences in the range of motion revealed females to have a significantly higher excursion in axial rotation then males. The regression equation indicated significantly ($p<0.001$) more axial rotation in females than males with a difference of approximately 3.5 degrees. This trend was significant in both left and right directions.

Buchalter et al (1986) reported no relationship between ranges of motion and gender. However, readings from the mean values of his histogram indicated females to have higher axial rotation values than males.

Hindle et al (1990) et al reported higher mean excursions values for females than males but when tested by ANOVA no significant differences were found.

Russell et al (1993) reported significant differences between males and females in the 40-49 and 60-69 age groups with females having significantly higher excursion values than males.

Based on the results from these 4 studies there is evidence to suggest that females display more axial rotation than males in the healthy lumbar spine. The present study indicates that females posses 3.5 degrees more axial rotation per side than their male counterparts.

Height was shown, in the present study to be significantly related to axial rotation to the left but not to the right. However, the p-values for the slope were only marginally significant and it is unlikely that any clinical significance could be attributed to this finding. None of the other studies reported correlation values for height and it is therefore unlikely that height plays a significant role in axial rotation mobility in the lumbar spine.

The present study also found axial rotation to be related to mass. As for the other movements, only Russell et al (1993) suggested that heavier people could be expected to have greater skin movement which would affect the readings obtained by causing the sensor to move a greater distance relative to the underlying vertebrae. When correlating weight and RoM however no statistical significance was seen. Based on the linear regression equation in the present study it can be concluded that an increase of 10 kilograms is associated with a loss of 1 degree of axial rotation.

Summary and conclusion for the gross movement of axial rotation

Close agreement between the present study and other 3 Space Isotrak studies exists. These studies suggest that, on average, 13 degrees of axial rotation to each side can be expected from the healthy human spine. No X-ray values were found for comparison. Based on data from in vitro studies, 3 degrees per lumbar segment can be expected. Therefore, ±18 degrees of axial rotation to each side could be expected to be recorded in the healthy lumbar spine at most. A small decrease in axial rotation mobility with age can be expected. Gender seems to play an important role in axial rotation mobility with females having significantly higher values then their male counterparts. Height, does not seem to affect axial rotation mobility to a major degree. Mass in contrast, appears to play a significant role in reducing axial rotation mobility with 1 degree loss for every 10 kilos increase in mass.

Finally, it can be concluded that when healthy subjects perform axial rotation small amounts of organised and individual coupling occurs but further work is required to confirm in which plane significant coupling occurs.

13.3 Analysis of 4 functional movements

13.3.1 Introduction

Return to work is often evaluated by functional capacity testing (Mayer and Gatchel, 1988). Evaluating functional capacity is predominantly done by testing of strength (Nelson and Nester, 1988), Range of motion (Mayer and Gatchel, 1988) and/ or simulation of specific job tasks.

Accurate job simulation may be difficult to achieve in a clinical environment. Therefore appropriate tests, incorporating, RoM in the three planes simultaneously have to be used in order to determine true recovery and successful return to work.

Several authors have shown that injury might influence coupled trunk motion in vivo (Marras and Wongsam, 1986, Oxland et al, 1992; Masset et al, 1993). Therefore quantification of these movements may provide important information for lumbar spinal functional capacity evaluations. No literature was found where functional capacity related to excursions tests for the lumbar spine was described.

Sitting down and rising up from a chair and ascending and descending stairs are functional activities necessary for normal daily living. Little information is available on how the lumbar spine moves during these activities. Furthermore, no information is as yet available on how low back pain patients perform these activities of daily living. It was considered important to include a functional task where a large amount of lumbar flexion was combined with axial rotation as this combination is known to increase the load on the intervertebral discs. Picking up an object at the side bringing it in front of the subject and then putting it down at the other side simulates this functional movement and is thought to include large rotations in

3 dimensions. A better understanding of the normal movements during these activities would help the clinician's assessing the effect of a therapeutic intervention and speed up the return to function.

13.3.2 Assessing "sitting down and standing up from a stool"

From the plots in figures 10.26 and 10.27 it can be seen that the subjects started the movement with 5 degrees of extension. They then performed a forward bend while sitting down and extended again when sitting. They remained in that position for a while then performed a similar degree of forward flexion and extension when rising to stand. No noticeable organised coupled movements were observed. The individual traces revealed few outliers, indicating that this movement was performed in a consistent manner.

Healthy subjects used approximately 60% (table 10.21) of their available flexion range to perform this movement, indicating that sagittal mobility of the lumbar spine plays an important role in this daily activity.

13.3.3 Assessing going up and down a step.

This functional activity puts a higher demand on balance and proprioception then the other movements. Therefore, it would be reasonable to expect a higher degree of compensatory motion displayed in the form of coupled movements. This was indeed the case. From table 10.30 it can be seen that the movement was performed starting from 5 degrees in extension, bending forward and simultaneously bending and twisting to the left. It has to be remembered that all subjects started the movement with their left foot first. A mirror image pattern was seen during the descending phase.

Going up and down a step requires, on average 25% of a persons ability to flex in the sagittal plane. It thus requires substantially less RoM than sitting down and standing up. However, this movement required 51% of the maximum range in lateral bending and 48% of the axial rotation, suggesting that this test provides more information on a person's ability or limitation in the use of 3 dimensional movements.

13.3.4 Picking up a box at the left side and putting it down at the right

This test was designed to assess the excursion capacity of the lumbar spine during combined movements. Figure 10.30 reveals a smooth forward flexion movement which is combined with a left lateral bending and axial rotation followed by a return to the standing position. The movement is then repeated to the right with a similar degree of forward flexion, right lateral bending and axial rotation.

Similar patterns and values were recorded for the movement of picking up a box to the right and putting it down at the left. The conclusions drawn for the mirror image to the left therefore also apply here. This test, to the opposite side, was included in order to differentiate between affected sides in low back pain patients.

From table 10.25 it can be concluded that a high degree of forward flexion was used (85% of the available range) It is remarkable that the excursion values for both coupled movements actually exceeded the values obtained in the primary gross movements (35 degrees in the functional movements versus 22 degrees in the gross movement for left bend and 15 degrees in the functional movements versus 14 degrees in the gross movement for axial rotation). These findings suggest that the lumbar spine can obtain a higher excursion values in a combined motion then in "pure" gross movements. This implies also that left side

bending was "limited" when pure gross movements were recorded in this study. It further suggests that studies where 35 degrees were reported may also have been correct but that there was a lack of care in their instructions and therefore pure gross sidebending was not produced. In contrast, the bony contact of zygapohyseal joint limits the maximal axial rotation to 3 degrees per segment therefore the values are similar in the functional and gross movements and still remain below 18 degrees of motion.

In conclusion, the functional tasks were carried out in a smooth, rhythmical fashion and using substantial coupled movements in three dimensions. The functional tasks represent a greater movement challenge to the lumbar spine than that produced during the gross anatomical movements.

13.4 Summary and conclusions on normal spinal kinematics

- The 3 Space Isotrak goniometer system was a relatively easy to use tool for recording lumbar spinal motion in healthy subjects. The device was able to record small changes in spinal motion. In addition coupled movements were recorded reliably and consistently allowing kinematic patterns to be established in 6 gross movements and 4 functional tasks.

- Close agreement, between the present study and 3 other studies using 3 Space Isotrak devices exists for normal RoM in the lumbar spine. It can be concluded that, on average, the lumbar spine will display

  56 degrees of forward flexion

  22 degrees of extension

  24 degrees of lateral bending to each side

  13 degrees of axial rotation to each side

  These values are also in close agreement with values recorded by X-rays.

- It would appear that 3 Space Isotrak values reflect the true movement of the lumbar spine as indicated by X-rays. Other 3 D devices using a different technology reported values in excess of X-ray values and with greater inconsistency.

- Healthy subjects conducted the six gross movements in a smooth and direct fashion without major disruptions or compensations. They started from a standing position of 5 degrees of extension and returned to that position after completion of the movement.

- Healthy subjects performed forward flexion and extension in a pure fashion without significant coupled motions. It would appear that lateral bending is associated with a degree of forward flexion and axial rotation with sagittal and frontal plane motion.

- Evidence was provided to suggest that age reduces the amount of mobility in the 6 gross movements examined and that females on average display a higher mobility than their male counterparts.

- Functional activities, consisting of large amplitude coupled movements, provide a better indication of lumbar spinal mobility then gross movements as the excursion values for both coupled movements actually exceeded the values obtained during the primary gross movements.

14. Discussion: Differences between healthy subjects and acute/subacute low back pain patients.

14.1 Introduction

In this chapter the differences in spinal kinematics produced by low back pain in acute/subacute LBP-patients will be discussed. Only one comparable study (Hindle, 1989) was found in the literature reporting the use of a 3 dimensional electro-magnetic goniometer to discriminate between healthy subjects and LBP-patients. However, the methodology used differed from the present study. These differences are outlined in the following section.

Hindle, (1989) reported on LBP-patients (n=31), assessed by orthopaedic surgeons, in an outpatient clinic. A diagnosis, based on the anatomical structure at fault, had been given to every patient and all patients were awaiting surgery. Furthermore, all patients had a history of LBP-pain lasting longer than 1 year and all had radiating pain to one or both legs. Hence these subjects were chronic low back pain sufferers awaiting surgery for mechanical low back pain. The present clinical trial (n=41) only included LBP-patients with "non-specific" LBP i.e. no radiating pain to the legs. Patients were assessed by a physiotherapist before inclusion and no specific diagnosis, related to anatomical structures, had been made. However, a common feature for all patients included in the present study was that the patients were deemed suitable, by the assessing physiotherapist, for manual mobilisation i.e. suffering from hypomobility. Furthermore, the patient group in the present study had a shorter history of low back pain (average 4 weeks, range 2-12 weeks) than in the study by Hindle (1989). In other words, the patients in the present study were acute/subacute low back pain sufferers with no evidence of a mechanical back problem and in whom mobilisation for hypomobility was considered valuable.

14.2 Comparison of gross movements

14.2.1 Introduction

Comparing figures 10.2–10.13 (healthy subjects) to figures 11.1–11.12 (patients) reveals that the 6 gross movements were performed, by the patients, using a similar pattern of movement to that exhibited by healthy subjects. No noticeable differences in the shape of either primary or coupled movements were apparent from the plots. Furthermore, the individual traces showed few outliers i.e. there was not much scatter in the data. The magnitude of the angulation, however, was substantially reduced in a number of movements.

14.2.2 Excursion plots

When comparing the interpolated mean plots for forward flexion of 100 healthy subjects (figure 10.2) with those of the 41 patients (figure 11.1) it can be seen that both groups started the movement from the same position, in both primary and coupled movements.

During the test, the forward flexion excursion was substantially reduced in the patients relative to the healthy subjects group. After performing forward flexion they came back to the same starting position, indicating that no displacement of the measuring device took place in either group. The pattern of motion was similar in both groups and involved a pure forward flexion with little organised coupled movement. However, a slight increase in organised coupled right lateral bending occurred in the patient group (figure 11.1). The overall impression however, is that the movement pattern was similar in both groups and involved a pure forward flexion with little organised coupled movement. Comparing the individual traces (figure 10.3 & 11.2), it can be seen that in both groups some subjects

performed coupled movements to the right and some to the left, with no overall trend. This was similar in both groups.

For extension (figures 10.4 and 11.3), many similarities to the result for forward flexion can be seen. In both groups the subjects started and ended the movement in the same position. The movement was performed in an undisrupted and smooth manner, without any organised coupling occurring in both patients and healthy subjects groups. The amount of extension produced by the patients was again reduced.

For lateral bending (figure 10.6 & 11.5) similar patterns were apparent for the patients and healthy subjects with the patients showing reduced lateral bending excursion. Noticeable organised coupling of left and right lateral bending with forward flexion occurred. This was apparent in both the healthy subjects (figures 10.6 and 10.8) and patient (figures 11.5 and 11.7) groups. Observing the individual traces, very few outliers could be seen, although some subjects appeared to have very pronounced lumbar lordosis angles as apparent from the starting position in extension. For lateral bending the starting position and the end position were similar indicating that no displacement of the sensor occurred in either group.

Finally for axial rotation (figure 10.10 and 11.9) a similar picture was seen with the patients performing the gross movement of rotation in a similar way to the normal subjects but with a reduced excursion. Noticeable organised coupling, in both groups, could be observed from the plots of axial rotation to the left (figures 10.10 and 11.9) where a few degrees of extension occurred. However, no such coupling pattern was observed when rotating to the right (figures 10.11 and 11.10) in either group. This indicates that asymmetry in findings was consistent in both groups giving further weight to the conclusion that the movement is performed slightly differently to the right than to the left. This may be an anatomical difference due to hand dominance or due to the instructions and protocol used in the test. The organised coupling was of the order of 1 or 2 degrees. In conclusion, some coupling in

the sagittal plane occurs when performing axial rotation with this coupling predominantly occurring as extension.

Summary

For the gross movements of forward flexion and extension no organised coupling was apparent, in both healthy and patients groups. Identical coupling for both groups was present for the movement of lateral bending which was coupled to forward flexion. Finally, axial rotation to the left was coupled to extension in both groups. In conclusion, no noticeable differences in coupling patterns between LBP-patients and healthy subjects were apparent. However, the excursions used for the primary movement were substantially reduced in the patient group.

14.2.3 Excursion values.

Table 11.3 displays the mean excursion values associated with the primary and coupled movements and a comparison of these between patients and healthy subjects. The coupled movement values were very similar in both patients and healthy subjects groups. For flexion a difference of 0.1 degree in lateral bending and 1.3 degrees in axial rotation was present. Extension gave identical values for lateral bending and 0.1 degree in axial rotation. Lateral bending to the left and right gave differences for flexion-extension of 1.9 degrees and 1.5 degrees and for axial rotation of 0.3 and 0.0 degrees. Axial rotation to the left and right gave a difference for lateral bending of 0.7 and 0.2 degrees and for flexion-extension of 1.3 and 0.6 degrees. Because of the small value of these differences it can be concluded that only minor differences in coupled movement values were present when comparing healthy subjects to acute/subacute LBP-patients.

Important differences, however, were apparent in the primary movements (table 11.3) with 4 out of 6 movements significantly different between patients and healthy subjects on a alpha level of $p<0.008$ and 5 out of 6 on an alpha level $p<0.05$ (table 11.4). Forward flexion was reduced by 12.3 degrees on average (95% CI: 7.6-17.0 degrees) from the mean value of 55.4 degrees recorded by healthy subjects. This represented a reduction of 22.2% (12.6 % to 30.6 %) of the mean value for healthy subjects. Extension was reduced by 7.5 degrees on average (95% CI: 3.82 to 11.13 degrees) from the mean value of 23.1 degrees recorded by healthy subjects. This represented a reduction of 32.4 % (16.5% to 48.1%) of the mean value for healthy subjects. Lateral bending to the left & right were reduced by 3.6 & 3.9 degrees (95% CI: 1.15 to 5.89 & 1.37 to 6.37 degrees) respectively, from the mean value of 21.7 & 22.8 degrees recorded by healthy subjects. This represented a reduction of 16.5% & 17.1% (5.1% to 27.1% & 6% to 27.9%) of the mean value for healthy subjects. Axial rotation to the left & right were reduced by 1.6 & 2.2 degrees (95% CI: 0.41 to 3.71 degrees & 0.13 to 4.1 degrees) respectively, from the mean value of 14 & 13.5 degrees recorded by healthy subjects. This represented a reduction of 11.4% & 16.2% (2.9% to 26.5% & 1% to 30.8%) of the mean value for healthy subjects.

The results for the primary movements clearly indicated that acute/subacute LBP-patients displayed restricted primary movements, of the order of 10 to 35%, compared to healthy subjects. Therefore, these patients clearly suffered from hypomobility in the lumbar spine and would appear to have been suitably selected for a mobilisation treatment by the assessing physiotherapist.

The only other study assessing a patient group using a 3 Space Isotrak was by Hindle (1989). Thirty six patients who where being considered for back surgery were assessed by

two orthopaedic surgeons. There was a large range of pathological conditions present in the patients, but combining them together in general groupings of those with clinically similar features permitted four groups, with at least five individuals in each group, to be identified. There were two groups in whom the primary source of pain was diagnosed as being associated with an intervertebral disc called disc1 and disc 2, one group in whom the primary source was associated with lateral recess restriction called lateral recess and one group in whom zygapophysial joint arthropathy was diagnosed called facet joint group. A comparison of the movement patterns of each patient to a normal group matched for age and gender showed that all the patients had widespread and marked deviations from normal in both primary and coupled movements for 6 gross movements. Although significant differences were reported between the patient group as a whole and the healthy subjects no significant differences in pattern between the different patients group was reported.

The results of Hindle's study are in agreement with the present study when considering the primary movements but disagree regarding the coupled movements. Furthermore, Hindle (1989) reported not only differences in magnitudes of movement but also in the relationship between the primary attempted movement and the movements in the other planes. No such change in kinematic pattern was recorded in the present study.

The attachment system used in Hindle's study probably allowed more skin movement, leading to an altered motion pattern, whereas in the present study no movement of the sensor on the skin was noticed. Therefore the movements recorded in the present study where likely to be a true reflection of the movements of the lumbar spine. Another reason for the differences noticed between the two studies might have been the difference in patient sample selected i.e. chronic patients in Hindle's study and acute/subacute patients in the present study. Further research is needed to confirm if chronic LBP-patients display compensatory movements whereas acute/subacute patients do not show compensating

movements when performing gross movements. If this difference is indeed confirmed then this could be used in prognostic, assessment and the treatment process of LBP-patients. It might be possible that chronic LBP-patients, over time, learn how to compensate for pain and restricted excursion in the primary movements whereas acute LBP-patients display a more rigid movement pattern, keeping the lumbar spine rigid allowing as little movement as possible.

In conclusion, the patient group performed the gross movements in a pure fashion similar to that of the normal subjects. A significant reduction in the primary motion for each gross movement was apparent. However, no change in excursion values of the coupled movements during any of the gross movements was seen.

14.3 Comparison of 4 functional movements

Comparing plots from figures 10.26 - 10.33 with figures 11.13 - 11.20 reveals that the functional movements were also similar in the healthy subjects and patients groups. No different pattern of organised coupling or extra movements were observed. The movements were performed in the same way although small disruptions during the execution of "sitting down and rising from a stool" (figure 10.26 & figure 11.13) were noticeable in the patient group.

The excursions values showed the same trend as in the gross movements i.e. a decrease in the primary movement values. This trend was significant ($p<0.05$) for 3 out of the 4 tasks. Only in "sitting down and rising up from a stool" did the reduction in excursion values not reach significance level (table 12.8)

When considering the organised coupled movements, however the trend was different from that found in the gross movements. Whereas in the gross movements only small differences in coupled movement values were reported, significant differences were seen in the coupled movements during functional tasks (table 12.8). In "sitting down and standing up from a stool" a significant (p=0.03) increase in the coupled motion of lateral bend and axial rotation (p=0.008) occurred while a non-significant, but borderline decrease in the primary movement of flexion was noted (p=0.055). During "going up and down a step" a non-significant decrease in lateral bending (p= 0.419) and axial rotation (p=0.359) occurred and the primary movement was significantly decreased (p=0.001). Both primary and coupled movements were significantly decreased in the two "picking up a box " movements (table 11.12).

It is interesting to observe that significant decreases in excursion values in the coupled movements were seen in the "picking up a box" tasks but not in "going up a step". This suggests that differences in compensatory movements are more easily detected in functional tasks where coupled movements of large excursion are combined i.e. "picking up a box". Picking up a box at the side and putting it down at the other entails large amplitudes of forward flexion, axial rotation and lateral bending occurring simultaneously. Therefore, these 3 dimensional functional tasks are likely to put the structures of the lumbar spine under a higher degree of stress than that seen during gross movements or planar functional movements. The significant decrease in primary movement excursion values during functional tasks is in agreement with the results seen in the gross movements.

The overall conclusion of this comparison between healthy subjects and patients suffering from non-complicated acute/subacute low back pain is that there is indeed a significant reduction in mobility displayed by LBP-patients. These findings, for acute/subacute subjects

are in contrast to previous reports that range of motion measurement methods demonstrated no consistent relationship to the level of physical impairment in subjects with chronic low back pain (Nattrass et al, 1999). Further work will be required to establish whether this relationship can be confirmed in acute/subacute subjects and whether acute and chronic sufferers are different in this regard.

The results from the present study suggest that acute/subacute LBP-patients perform gross movements without compensatory, out-of plane movements, but that during 3 dimensional functional tasks of large amplitude these movements are significantly decreased.

The purpose of a clinical assessment is to provide the clinician with information on the available maximal painfree excursion in both primary and coupled movements. As performing gross movements and planar functional tasks does not seem to require a large degree of coupled movements the use of large amplitude 3 dimensional functional tasks to assess lumbar spinal kinematics would appear to be indicated in preference to the gross movements. The use of large amplitude 3 dimensional functional tasks appears to give a more comprehensive assessment of the 3 dimensional mobility of the lumbar spine than the use of the conventional analytical gross movements. Finally, assessing 3 dimensional motion characteristics of the lumbar spine can facilitate the use of new, dynamically based biomechanics research to assess the risk of lumbar injuries in the workplace.

15. Discussion: The immediate effect of a low-velocity mobilisation treatment on patients with acute/subacute low back pain and lumbar spinal hypomobility.

15.1 Introduction

A randomised controlled clinical trial, including 41 LBP-patients, was carried out in order to investigate the immediate effect of low-velocity mobilisations on pain and lumbar excursion in "non-specific" LBP. These effects where identified in two different groups of patients i.e. an "intervention" group, who received the treatment immediately after a flexibility measurement and a group called "delayed intervention group", who received the same treatment but delayed by 1/2 an h. These two groups were tested on three occasions within 3 hours. This chapter will discuss the consequences of the differences between and within the different patient groups as well as the effectiveness of a manual mobilisation treatment. Based on the results of this randomised clinical trial and the literature, the evidence for the use of manual therapy techniques in acute/subacute low back pain patients will be considered.

15.2 The immediate effect of a low-velocity mobilisation treatment on lumbar excursion in non-specific LBP.

A one-way analysis of variance (ANOVA) for repeated measures design was used to statistically analyse differences between and within the groups during six gross movements and over three test sessions. Significant differences were detected between the groups in two out of the six gross movements (forward flexion and axial rotation to the right). Further post-hoc analysis, using independent and paired t-tests revealed significant differences in 5 out of 22 possible combinations (chapter 12: results).

For the gross movement of forward flexion, a significant decrease (p=0.04, paired t-test, 2-tailed) in excursion was recorded in the intervention group between test 1 and test 3 i.e. before to one hour after the intervention (from 41.1 degrees before the intervention to 38.1 degrees after the intervention and rest). This would imply that a mobilisation led to a decrease in forward flexion flexibility in the intervention group. The delayed intervention group had a significant decrease ($p<0.008$, paired t-test, 2-tailed) after the first measurement and 0.5 h rest (from 44.7 degrees after the first measurement to 39.4 degrees after 1/2 h rest). However, after the intervention their mobility came back to the same level as after the first measurement (from 39.4 degrees after rest to 44.4 degrees after intervention. This difference was significant (p=0.009, paired t-test, 2-tailed). In other words, the intervention group did not have an increased lumbar flexion mobility, when they left the clinic. Furthermore, the size of the increase and decrease in excursion value for forward flexion (table 11.4) was small but significant (mean difference 5 degrees, 95 % CL 1.5 – 9 degrees) in relation to differences seen between healthy subjects and patients (mean difference 12.3 degrees, 95 % confidence intervals 7-17 degrees). The only significant difference in mobility between the first and third test, was detected in the intervention group where indeed a significant (p= 0.04) decrease (from 41.1 degrees to 38.1 degrees) in flexibility was recorded. Therefore, it can be concluded that the subjects had not improved their flexibility status in forward flexion when they left the outpatient department and that a low velocity mobilisation had no immediate positive effect on the patients' flexibility status during the gross movement of forward flexion.

For the gross movement of axial rotation to the right a significant increase was recorded (p=0.000, paired t-test, 2-tailed) in the intervention group immediately after the intervention (from 11.4 degrees before the intervention to 13.9 degrees after intervention). However,

after 0.5 h rest the values were close to pre-intervention again i.e. a significant decrease occurred during the rest period (p=0.035, paired t-test, 2-tailed). Therefore, it could be concluded that any gain in mobility seen during axial rotation to the right was of a temporary nature. However, the size of the increase and decrease in excursion value during axial rotation to the right was substantial, relative to the excursion values obtained in healthy subjects. The intervention group had an increase of 3.5 degrees, 95% CI 1.7-5.1 degrees, (from 10.4 degrees to 13.9 degrees after intervention) whereas the difference between healthy subjects and patients for axial rotation was 2.1 degrees, 95% CI 0.1-4.1 degrees (table 11.4). This significant increase in primary excursion value, however, was not maintained and was reduced to 11.9 degrees after 1/2 hour rest (table 12.1). A similar increase was not recorded in the delayed intervention group where in fact a small decrease (from 13.9 degrees to 11.9 degrees) was recorded after the intervention i.e. between test 2 and test 3 (table 12.1)

Neither the intervention nor the delayed intervention group recorded a significant increase in flexibility from test 1 to test 3 for the gross movement of axial rotation to the right. Therefore it can be concluded that no sustained increase in axial rotation flexibility was gained from a mobilisation treatment.

The excursion values for primary and coupled movements during 4 functional tasks were compared over 3 tests (table 12.7). Only minor changes were recorded between the different tests in the two patients groups (maximum difference of 1.9 degrees (table 12.8) in axial rotation during picking up a box at the right side. Moreover, when comparing the primary and coupled movement values obtained in test 1 and test 3 a decrease in flexibility could be seen for 15 out of 24 possible comparisons (table 12.7). In conclusion, the present

study could not demonstrate any clinically significant increase in lumbar flexibility during functional tasks after the application of a low velocity manual mobilisation.

It was hypothesised that a low velocity mobilisation would result in the values of the patient groups becoming more similar to those of the healthy subjects. This did not occur. The consequences of a temporary significant increased flexibility in only 1 out of 6 gross movements (axial rotation to the right) indicated that this effect is likely to be related to sample size or chance and hence it can be concluded that no increase in lumbar mobility occurred. Furthermore, the patients did not perform the functional movements differently or with more ease and using larger excursions after a mobilisation. The results of the functional tasks therefore confirm what was seen during the gross movements with no improvement in lumbar flexibility occurring. One is forced to conclude that the mobilisations administered to this LBP-patients group did not improve the mobility of their lumbar spine and that a low velocity mobilisation in this group was ineffective as a treatment modality for reduced lumbar flexibility. This is in contrast to the stated aims of the Maitland mobilisation system.

15.3 Generalisability and External Validity of the results

Bracht and Glass, 1968 cited several sources of external validity which needed to be addressed in order to deal with representativeness and generalisation of the data to the general population. In the context of this study and generalising the data to the Scottish population of LBP-patients Bracht and Glass's work indicates the following issues should be addressed:

- Sample representativeness
- Patient inclusion rate
- Differences in treatment regimes administered

These points are addressed in the following sections.

15.3.1 Did the sample studied really represent the population ?

The sample selected was intended to be representative for acute/subacute LBP-patients in a Scottish population. As more stringent controls are applied to an experiment less realism can be achieved or be expected between the findings and situations outside the experimental settings (Currier, 1984). In the present study a pragmatic clinical trial i.e. a real day to day situation was used with as few changes in the daily treatment routine of the department as possible.

In order to ascertain that the patient sample represented a true reflection of a Scottish LBP population the disability scores for the participating patients were recorded. A Roland Morris disability questionnaire (RMQ) was used to record information on the disability status of a group of low back pain patients (n=41) and to compare this status to that recorded in comparable studies. In doing so, we could assess if this patient sample was representative or different from a wider population with respect to disability status.

The RMQ was selected because it is one of the most frequently cited self-report and condition specific measure, applied to back pain patients. Moreover, the measurement properties of RMQ are equal to or better than competing functional status measures (Stratford et al, 1994). The measurement score goes from 0 to 24 and represents the number of "yes" answers on 24 questions related to daily activity tasks.

The LBP-patients in the present study obtained a mean RMQ-score of 10.1 (chapter 9, section 9.2.2) which was similar to the mean "customary" score of 11.1, reported at admission, in 7 clinical trials (chapter 8, section 8.6) reported by Stratford and Binkley

(1999). These authors used the term "customary" values because normal values do not, at present, exist for condition-specific measures such as the RMQ.

High among the reported difficulties were the impact of pain on comfort i.e. change position frequently to try and get back comfortable (78%) and sleep less well (58%). However, functional restrictions were also prevalent (difficulties getting on socks (63%), walking more slowly (58%), and difficulties getting in & out of a chair (56%)). In contrast, in only one case out of 41 was back pain reported so intense that the patient stayed at home most of the time and none reported that they stayed in bed most of the time because of back pain.

In conclusion, the findings from the present study suggest that LBP-patients in this study showed similar disability scores to previous reported clinical studies. A mean score of 10-11 can be expected for patients suffering from non-specific acute/sub-acute LBP. Our experience with the RMQ, from the present study, supports the use of the RMQ as an easy to use tool for clinical decision making by physiotherapists. Its application increases the confidence that the clinician has in assessing disability without increasing patient treatment time. Further, most patients in this study described their disability more as a discomfort than as a pain. This discomfort did not affect their independent way of life.

15.3.2 Was the patient inclusion rate typical?

A large variation in patient inclusion rate existed between the different physiotherapists (chapter 9, figure 9.1). The average inclusion rate for the six participating physiotherapists was 1 out of every 4 patients assessed (22.7%). It is generally believed that LBP causes hypomobility and restricted movement. Also, hypomobility is reflected by the high disability

score of functional movements like difficulties in rising from a chair (chapter 9, table 9.4). Furthermore, it is widely accepted that mobilisations are an integral part of the physiotherapy treatment for low back pain and that they are effective in the treatment of hypomobility. All participating physiotherapists in this trial indicated, prior to the trial, that they used low velocity mobilisation techniques for LBP on a daily basis. It was therefore surprising that such a low inclusion rate was seen. A number of explanations present themselves as to why such a limited number of patients were deemed suitable for inclusion in the trial.

- The 6 physiotherapists all volunteered to participate in the trial. However, all were fully aware of the fact that this trial involved an evaluation of the efficacy of a commonly used treatment technique in physiotherapy. Therefore it is possible that the participating physiotherapists were more restrictive in their inclusion rate than in their daily practise and only included LBP-patients where a treatment effect could be expected. One way of confirming this would have been to trace back the individual physiotherapists use of a mobilisation treatment during a period before the trial. Unfortunately this was not done as all therapists indicated using mobilisations on a daily basis. Moreover, the six physiotherapists included in the trial all confirmed that the majority of low back patients seen in their clinics would be treated by manual mobilisations techniques. A consequence of the low inclusion rate was the patient recruitment time and in fact the total time of the trial prolonged by 3 months.
- It might well be that these findings are the true reflection of the actual popularity or user frequency of mobilisations in a busy NHS outpatient clinic in Scotland and that the physiotherapists actually use mobilisation treatments less frequently than they reported. The outpatient clinic in the trial dealt with a variety of conditions and could arguably be

labelled as a "specialist" LBP clinic. All the physiotherapists involved in the trial had extensive experience in the treatment of LBP. Therefore it can be assumed that this out-patient department reflected, at least, the average practice in a Scottish NHS clinic.

- Good mobility or hypermobility was often used as the reason why a physiotherapist didn't include a patient in the trial (table 9.2). This seems logical as good mobility would imply that mobilisation treatments were not indicated. However, physiotherapists' assessment of patients' movements was subjective, consisting of mainly an assessment of gross movements and was based upon identifying any restriction in a patient's movement by eyeballing or palpation. Hindle et al (1990) demonstrated that clinical subjective assessment of back mobility bore little relation to the true movements and that therefore the clinical measurement of back movements should be reassessed. The present study, as other studies before, indicated that the assessment of three-dimensional movements of the lumbar spine is a complex process. Therefore, the subjective assessment by eye or palpation should be considered of limited use and may have excluded patients that might benefit from mobilisation.
- Finally, it is also possible that a majority of patients had already partially or entirely recovered from their LBP with little or no limitation in mobility remaining. The inclusion criteria included acute and subacute low back pain patients i.e. patients who had their pain from 0 to up to 3 months in each pain period. As the majority of the low back pain patients recover within 3 months there was an increased possibility that a certain number of patients were assessed who did not have severe enough symptoms to justify a treatment. However the physiotherapists judged that they would benefit from the treatment.

In conclusion, there may be some evidence to suggest that the therapists selected only those patients who they confidently expected to gain benefit from the treatment. The failure of this selected group to gain benefit from the treatment implies that a more general group would also not benefit.

15.3.3 Were there differences in the treatment administered?

Sometimes subjects are exposed to more than one manipulated independent variable which makes the interpretation of the results difficult and threatens the external validity of the project. In the present study this might have been other physiotherapy treatments like electrotherapy, traction, massage, exercises etc. However, in the present study no treatment additional to mobilisation was recorded. All six participating physiotherapists applied a mobilisation treatment only during the treatment session. The treatment given was recorded on a recording sheet and subsequently compared with that given by the other physiotherapists. No differences in grades used or spinal level mobilised were noticed. and no additional treatments were given during this treatment session. It can therefore be concluded that the treatment administered was conventional within the Maitland system which is the most frequently used in the UK and that no different treatment modalities were used.

15.4 The immediate effect of a low-velocity mobilisation treatment on lumbar pain in non-specific LBP.

Several textbooks advocate the use of low-velocity mobilisation techniques specifically for the treatment of pain relief. Maitland (1986) stated that

" It is by restoring normal movement that the patient's symptoms will be relieved".

Furthermore, Brucker and Khan (1993) suggested that mobilisations are used to reduce pain and to restore movement to a hypomobile joint. Kaltenborn (1993) and Mulligan (1995), two pioneers of the use of low velocity mobilisations are even more specific by emphasising that the effect

of the techniques with regard to pain relief and/or increased mobility should be immediately apparent after a treatment session.

> " OMT will help the patient either in the form of a reduction of pain or by an increase in mobility i.e. a bedridden patient will be mobile again or a work incapacitated patient will be able to work again." It is emphasised that manual therapy should be effective immediately after a treatment session. Only the immediate effect after a treatment session could be attributed to the mobilisation, because long term effects could as well be attributed to the time aspect " (Kaltenborn, 1993).

Mulligan (1995) stated that

> " all the mobilisation techniques in this textbook are expected, when indicated and used, to bring about an immediate improvement in the patient's condition. A failure to do so would suggest the techniques are not appropriate for this patient or perhaps have not been undertaken correctly. On all my courses I say to the participants that if no improvement is evident at the time of delivery then discard the technique and try another approach and they should not be continued if some of the improvements were not retained between visits. Spectacular results are often attained and I expect in my practice at least one "miracle" a day using these techniques".

Despite the popularity of these techniques and the plethora of textbooks advocating them, little scientific evidence for their immediate effect on pain and/or excursion in LBP exist

(chapter 3). The findings of the present study suggest that acute/subacute LBP-patients, on average, present with a mild degree of pain measured by a visual analogue scale.

Although most of the 19 studies included in the literature review in the present study included pain as an outcome measure, none of these pain measurements were administered before and after one treatment session but merely after an entire treatment period. It is therefore difficult to attribute a pain reducing effect to the intervention as the time aspect plays an important role in the recovery of LBP. Only the study by Farrell and Twomey (1982) reported an immediate decrease in pain levels after mobilisation and manipulation (predominantly mobilisation) However, no p-value was reported. Terrett & Vernon (1984) studied the phenomenon of an immediate increase of pain threshold in LBP by measuring tolerance to electrically induced pain in paraspinal tissue before and after spinal manipulation and compared it to before and after mobilisation. Both groups showed increases in pain tolerance but the increase was significantly higher in the manipulation group. Vernon et al (1985) subsequently analysed serum β-endorphine levels before and after chiropractic adjustments and reported small but significant increases in serum β-endorphine levels. Sanders et al (1990), however, were not able to confirm this.

Although a reduction in mean pain scores was reported in the present study this did not reach significance level ($p<0.05$, Wilcoxon Matched-Pairs, Signed-Ranks Test and 2-tailed). A mobilisation treatment did not significantly alter the patients immediate V.A.S pain response. In fact, several patients reported increased pain levels immediately after the treatment. Many related this to localised pressure soreness on the skin overlaying the spinous processes mobilised. Furthermore, it has to be kept in mind that a V.A.S is a subjective measure of pain and although widely accepted as a measure of pain it greatly depends on the patients mood and relation with the therapist. Therefore it is suggested that future research on pain reducing effects of low velocity thrusts should include more

objective pain recording measures such as sensory pain threshold recordings in order to confirm or reject the subjective findings.

15.5 How does the findings of the present study fit with the current knowledge related to the effect of low velocity mobilisations?

The results of the present clinical trial are in agreement with the work on tissue mechanics presented by Lee (1995) indicating no sustained increase in flexibility between tests. Lee, (1990); Lee and Evans, (1991) and Lee and Evans, (1992) studied the mechanical behaviour of the spine in-vitro under loads similar to mobilisation. They suggested that a mobilisation produced creep and preconditioning effects. These effects however, were time dependent and therefore temporary. Lee (1995) further reported that any increase in distance between vertebrae was lost after 15 minutes.

15.6 What are the possible reasons for the lack of increase in mobility after a mobilisation treatment?

- Grover (1982) suggested that the mobilisation force applied has to be of sufficient intensity to produce failure or damage to scar tissue in the disc or soft connective tissue and thus cause an increase in segmental mobility. As no increase in overall mobility was shown during the present study it might be that the intensity with which the mobilisations were performed did not reach an high enough level to cause scar tissue damage. This is in essence the difference between high and low velocity thrusts and could be a possible explanation for the difference in efficacy between the two procedures.
- As pointed out earlier Lee, 1990, Lee and Evans, 1991 and 1992 showed that a posterior-anterior mobilisation produced creep and preconditioning effects which explained the immediate effect after a mobilisation in healthy subjects. However, these

time-dependent effects were temporary and disappeared after 15 minutes. The limited effects observed in the present study are in agreement with these findings and indicate no short term benefit.

- Haldeman (1994) indicated that one of the factors by which joint motion could be restricted is by limitation of joint play in the neutral position or at some point in the normal range of motion. Such joint play is usually for coupled movements and may be in planes other than the direction in which a joint usually moves. This author suggested that coupled movements are felt to be essential for the full smooth motion of a joint and treatment should be directed at restoring joint play. Therefore it is possible that the mobilisation techniques used in this study failed to address or treat the coupled movements.

Increase in range of movement can be regarded as the most widely accepted theory regarding the effect of both manipulation and mobilisation. Physiotherapy, osteopathy, chiropractic and medical practitioners alike have incorporated this theory. Wide consensus exists among these practitioners over the increase in excursion values and reduction of pain after a high velocity manipulation. However, this consensus does not exist for low velocity mobilisations. DiFabio (1992) concluded that nearly all of the valid efficacy studies on manipulation and mobilisation were pragmatic in nature: hence the clear need for additional explanatory research on high velocity thrusts. As valid pragmatic studies in low velocity thrusts are rare, it is even more difficult to find explanatory studies on the effects of a mobilisation treatment. However, the results of the present study indicate that a low velocity mobilisation, delivered in a typical way to a typical group of patients by typical physiotherapists failed to make a significant difference to the spinal mobility of the patients in gross anatomical movements and functional tasks. Given that so much time and faith is

currently vested by the physiotherapy profession on the use of low velocity mobilisations , these findings cause concern and require immediate and independent confirmation by the scientific community.

16 Clinical implications.

16.1 The clinical measurement system

Pearcy (1986) reviewed the techniques available for measuring back movement and pointed out the lack of a suitable system to measure three-dimensional functional movements of the back which would allow the clinician to confirm his/her subjective observations. If these observations could be made objective and quantifiable, it should then prove possible to examine the relationship between altered 3 dimensional movement and injury or disease and hence assist the diagnosis and treatment of back disorders.

In this study an existing 3 D electromagnetic device was adapted to make it a comprehensive measuring system suitable for use in a clinical setting, and able to be used in confined spaces e.g. within a busy physiotherapy outpatient clinic. The system was specially adapted for measuring 3 dimensional lumbar spinal motion in a reliable and time-effective manner. A series of validation experiments was carried out on the measuring device (3 Space Isotrak) in order to determine the accuracy and precision of the device. As a result of these validation experiments the operational range was limited from +70 degrees to -70 degrees giving an excursion of 140 degrees. This was considered suitable for the accurate measurement of normal and abnormal 3 dimensional lumbar spinal motion in a physiotherapy treatment and assessment context.

An identical device but with a different attachment and alignment system had previously been used once in a clinical setting (Hindle, 1989). However, some important differences between the two systems make the clinical implications drawn from these two studies also different. During Hindle's study the system was used to determine mobility in specific pathologies. Also, Hindle's study used a different attachment and calibration procedure to

investigate the work of 2 orthopaedic consultants, whereas in the present study the system was used in a physiotherapy outpatient clinic to investigate the work of 6 physiotherapists. Hindle's study, despite flaws with the attachment of the measurement device and difficulties in recording valid axial rotation values, concluded that the system was easy to use and gave valid information relating to lumbar kinematics in a clinical setting. However, the system was unable to detect differences in flexibility between groups with different clinical diagnoses.

The present study indicated that the 3 Space Isotrak system was a clinically effective method for the non-invasive three-dimensional measurement of lumbar spinal mobility. The system proved to be easily adaptable for use in a physiotherapy outpatient clinics. It was quick to set up and calibrate (average 10 minutes) and gave reliable and easy to read values of angles, in degrees. Furthermore, individual patient contact time for one measurement of gross lumbar movements took no more than 15 minutes. Compared to other systems, capable of measuring 3 dimensional motion, a vast improvement the 3 Space Isotrak is therefore highly efficient. The use of a lap top computer could further enhance the versatility and portability of the measurement system, allowing it to be used in different clinical environments such as patients homes, sports fields, research labs etc. Moreover, patients' compliance with the attachment system proved to be excellent. No complaints, vis-à-vis interference with respiration or mobility due to tightness of the attachment belts was recorded. The often reported draw-back associated with the measuring device i.e. the interference of nearby metal with the electromagnetic field and its influence on the measurements proved to be unjustified in this context. Therefore, the system proved to be well suited for use in a rehabilitation environment. However the application of the device over implanted material like fixation screws, might still put a limitation on its applicability.

The newly developed attachment and alignment procedure which was independent of computer control, proved to be very robust and easy to perform with the subject in a prone lying position. The prone lying position proved to be the most comfortable and stable position for the patient and the operator. Anatomical landmarks could be identified relatively easily. The adjustable belts allowed for a tight but still comfortable attachment to the skin. The results of the repeatability study indicated that similar results were obtained on different test occasions, under similar conditions. Therefore, it can be concluded that the values obtained are a true reflection of the mobility of the lumbar spine. Finally, the fact that the system has no mechanical linkage between the source and sensor module gives it some practical advantages over other 3 dimensional systems, especially when dynamic high speed movements are to be recorded.

The newly developed system is capable of recording small changes in 3 dimensional motion of the lumbar spine and has potential for use in the recording of high velocity dynamic motion. It is therefore suggested that this newly developed and adapted system could be used for future clinical research and also for routine use by physiotherapists to assess 3 dimensional lumbar flexibility in LBP-patients.

16.2 Assessment of acute/subacute LBP-patients.

Controversy exists in the literature whether lumbar flexibility is correlated to impairment and disability. Nattrass et al (1999) reported a low degree of correlation between impairment, disability and lumbar flexibility in chronic LBP-Patients. Other authors (Pope et al 1979, Mellin, 1987 and 1988; Tenhula et al, 1999) associated disorders of the lumbar spine with certain biomechanical changes in mobility characteristics of the spine in

acute/subacute LBP-Patients. Mellin (1989) further indicated that identification and quantification of these changes could be useful in specifying aetiology, prophylaxis and therapy. The results from the present study suggest that patients with acute/subacute low back pain have reduced lumbar mobility compared to healthy subjects. Impaired mobility was most clearly demonstrated during the functional tasks such as picking up a box at one side and putting it down at the other side i.e. tasks requiring large excursions. Both primary and coupled movements were reduced during these tasks. In contrast during the performance of the gross movements only the primary movements were reduced. Therefore, it is suggested that functional movements, requiring movements in different planes, should be used in clinical assessments of lumbar impairment instead of gross, planar movements.

The findings of the present study further confirm the need for 3 dimensional recording of lumbar spinal motion. The spine is a 3 dimensional structure allowing movements in different planes simultaneously therefore assessment procedures should be able to record changes in these movements simultaneously.

The results of this study are in agreement with a previous study by Pearcy (1993) where important differences in range of motion during axial rotation were recorded when measurements are taken with flexed hips compared to the anatomical position. Lumbar axial rotation was significantly increased when measurements were taken from a seated position i.e. with hip flexed. Futhermore, Pearcy (1993) suggested that increases in the gaps in the zygapophysial joints could be the cause for this phenomenon. Therefore, when the full excursion in axial rotation is to be assessed in LBP-patients, that this should be performed from the sitting position.

16.3 Low velocity mobilisation in the treatment of LBP-patients

Orthopaedic manipulative therapy techniques are meant to increase range of motion and/or decrease pain levels in patients suffering from LBP (Maitland, 1986) Low velocity mobilisations in particular are thought to bring about an immediate effect towards normalisation in joint play (Kaltenborn, 1993).

The results of the present clinical study have led to the conclusion that, at present, no evidence exist for the clinical efficacy of these techniques in acute/subacute LBP-pain and that some evidence exists, including the present study, as to the lack of a treatment effect. In the present study only temporary (15 minutes) and clinically irrelevant changes in low back mobility were recorded. In addition, no significant decreases in subjective pain recordings were seen in this group of patients which was selected for their ability to benefit from a mobilisation treatment. This indicates that the current OMT-practice for LBP is ineffective with regard to increasing lumbar spinal mobility or decreasing pain and that this intervention strategy does not fulfil the stated aims of the therapy for acute/subacute LBP. The lack of an immediate increase in lumbar movement or a decrease in pain indicate that the aims of orthopaedic manipulative therapy in the treatment of ALBP need to be reconsidered. In contrast, the existing evidence that a high velocity thrust can bring about an immediate increase in lumbar mobility and a decrease in pain suggests that some OMT practices may be effective in increasing mobility and reducing pain but that a Maitland low velocity mobilisation, is ineffective in attaining these goals.

Several OMT-approaches exist for the treatment of acute/subacute LBP (Maitland, Kaltenborn, Mulligan etc.) Although differences and similarities in techniques are apparent in all systems they all use predominantly low velocity techniques administered to the lumbar spine with the aim to restore "normal" mobility or obtain a reduction in pain. There is no evidence, at present, to suggest that one system is more beneficial than the other or that any

of the approaches has a beneficial effect on the spinal mobility of acute/subacute patients with LBP.

Despite the limited inclusion rate seen in the present study, mobilisation techniques are still very popular as illustrated by the number of postgraduate courses advertised in professional journals. Moreover, physiotherapy schools in the U.K. have included the teaching of these techniques in their curricula. Why is it then that these techniques remain popular and why have they been unchallenged for so long? Few pragmatic studies have been publicised where mobilisations have been scrutinised specifically in a clinical setting. This lack of research and enquiry into a fundamental area of physiotherapy practice reflects poorly on the profession. Given the costs of providing mobilisation treatment across the UK, the lack of efficacy seen in this study is of major concern. Further research is required as a matter of urgency in this area in order to establish or refute the clinical effectiveness of low velocity mobilisation techniques in LBP. However, some high quality studies, adding to the body of knowledge on the biomechanical basis of mobilisations, have been published (Lee, 1995; Lee and Evans, 1994) Although these studies challenged some traditional beliefs of the clinician they where basically laboratory studies and their external validity remains to be proven. The results of the present study confirm the findings reported by Lee (1995) and indicate that there is an urgent need for more clinical studies into the effectiveness of low velocity mobilisations.

It is incumbent on the physiotherapy profession and OMT practitioners in particular to provide and incorporate sound scientific evidence of the efficacy of the procedures and treatments used and relate this to both the aims and practice of physiotherapy.

17 Conclusions and Suggestions for further research

The aims and objectives outlined in the rationale for this study (Chapter 5, sections 5.2 and 5.3) have been met:

Aims

- A new measurement system, based on an electromagnetic measuring device (3 Space Isotrak) was developed. This newly developed system incorporated an appropriate and easy to perform attachment and alignment protocol which was independent of computer control.
- The repeatability of the newly developed attachment procedure was found to be high (Cronbach α: 0.871).
- A database for 3 dimensional lumbar spinal mobility, recorded in 6 gross movements was established. A database consisted of values for 5 age cohorts in males and females and an investigation of the effects of age, gender, height and mass. This database was used for comparison of patient values.
- The study established that acute/subacute low back pain patients display similar 3 dimensional kinematics patterns when performing gross movements compared to healthy subjects but differ significantly in the excursion values produced.
- The newly developed measurement system was successfully used in a clinical physiotherapy setting to investigate the effects of an orthopaedic manipulative therapy technique in patients of acute/subacute low back pain.

Objectives

- The measurement system was found to have similar accuracy and precision characteristics as reported in previous studies. However, due to the more comprehensive accuracy tests performed in the present study (accuracy was tested over 3 days and over the whole available measurement range i.e. ±90 degrees) it was suggested that the working measurement range should be reduced to ±70 degrees.
- The newly developed measuring system was found to be valid compared to X-rays and to give a fair representation of lumbar spinal movement. Concurrent validity with other 3 dimensional systems has been discussed. The excursion values obtained in this study represented the closest mean excursions reported in the literature when compared to X-ray studies.
- Testing protocols based on measurements of 6 gross movements and 4 functional tasks have been developed. Data analysis programmes producing interpolated data and categorising the data per movement executed have been produced.
- The repeatability of the measurements was confirmed in a group of 20 (10 male &10 female), 20 to 29 years-old by repeating the entire measurement procedure with a 3 hour interval. This study indicated that the system produced highly reproducible results when the same anatomical location was used.
- A normative database for 6 gross movements using 100 healthy subjects was established and used to compare and contrast the excursion values and movement patterns obtained by 41 acute/subacute LBP-patients.
- The effects of low back pain on lumbar spinal function were investigated using the newly developed measuring system. Patients suffering from non-specific low back pain displayed significantly reduced excursions in all primary gross and primary functional movements measured. Out-of-plane movements (coupled movements) were not affected

during gross movements but were significantly reduced during large amplitude functional tasks e.g. picking up a box at the side. However, no change in kinematics movement pattern was recorded.

- A randomised controlled clinical trial was carried out to investigate the immediate effect of a low velocity thrust on acute/subacute low back pain and decrease mobility. The experimental design adopted for this study showed to be valid for use in investigating the effects of an orthopaedic manipulative technique without withholding treatment from the patient.
- No evidence was found that immediate beneficial effects were produced by a low velocity mobilisation on the flexibility of the lumbar spine or in reducing subjective pain levels. The results from the present study challenge the conceptual framework regarding OM-techniques used in acute/subacute LBP and the author urges the physiotherapy profession to substantiate the clinical effectiveness of these techniques before they can be advocated in the treatment of lumbar hypomobility.

Conclusions

The hypotheses outlined in section 5.4 were tested and the following conclusions made:

1. Healthy subjects

A. Significant differences were found between young and older age categories in 5 out of 6 gross movements recorded.

B. Significant differences were recorded between males and females in 3 out of 6 gross movements with females showing higher mobility values then males.

C. Significant differences were recorded between gross movement excursion values taken in standing and sitting. A sitting position led to significantly increased values in 5 out of

6 gross movements. Only in forward flexion was a significant decrease recorded This was due to the abdominal mass obstructing the motion of forward flexion.

2. Subjects with acute/subacute low back pain

D. Acute/subacute low back pain patients showed significantly reduced excursion values for primary movements in 5 out of 6 gross movements tested.

E. Acute/subacute low back pain patients showed to have significantly decreased primary movements during 3 out of 4 functional tasks tested.

F. Acute/subacute low back pain patients showed significantly decreased coupled movements during 3 out of 4 functional tasks performed.

3. Effects of mobilisation techniques on acute/subacute LBP-patients

G. No significant differences in visual analogue scales were recorded before and after a mobilisation treatment in 41 acute/subacute low back pain patients.

H. No significant differences in visual analogue scale scores were recorded before and after a mobilisation treatment in acute low back pain patients (< 6 weeks of pain).

I. No significant differences in visual analogue scale scores were recorded before and after a mobilisation treatment in subacute low back pain patients (between 6 & 12 weeks of pain).

J. No significant differences in visual analogue scale scores were recorded before and after a mobilisation treatment in low back pain patients who received a treatment immediately after a measurement (intervention group).

K. No significant differences in visual analogue scale scores were recorded before and after a mobilisation treatment in low back pain patients who received a treatment after a measurement and 1/2 hour rest (delayed intervention group).

L. There were no significant differences recorded in excursion values between the intervention and delayed intervention group before a mobilisation treatment.

M. Significant differences were recorded within the intervention and delayed intervention groups over the three tests in 2 out of 6 gross movements i.e. in forward flexion and axial rotation to the right.

- A significant reduction in excursion value was recorded during forward flexion in the intervention group between test one and test three.
- A significant decrease in excursion value was recorded during forward flexion in the delayed intervention group between test one and test two.
- A significant increase in excursion value was recorded during forward flexion in the delayed intervention group between test two and test three.
- A significant increase in excursion value was recorded during axial rotation to the right in the intervention group between one and test two.
- A significant decrease in excursion value was recorded during axial rotation to the right in the intervention group between tests two and three.

Suggestions for further research

- Several types of 3 dimensional goniometry exist on the market today. Comparative studies are required to determine the concurrent validity of these systems and to determine the most clinically cost-effective device.

- A further development of a normative database for 3 dimensional motion measured by electromagnetic measurement devices with a substantial number of subjects in each age cohort is indicated. The databases developed in the present and previous studies are useful to demonstrate a certain trend in age or the differences in gender. However,

taking into account the widespread in normal mobility variation which exists between individuals it is difficult to distinguish between specific pathologies on the basis of decreased mobility.

- In contemporary clinical practice, subjective evaluation of mobility is the mainstream form of assessment among physiotherapists. Further work should determine if subjective clinical assessments, made by physiotherapists, are in agreement with the objective data obtained by 3 dimensional measuring devices.

- Controversy still exists in the literature regarding the influence of hip flexion on lumbar axial rotation. Further research using 3 dimensional measuring devices should investigate the effects of hip flexion in functional tasks involving axial rotation.

- The ability of the 3 space Isotrak to objectively record lumbar spinal kinematics in dynamic movements makes it possible to study dynamic motion of the trunk during the performance of work related tasks. These measurements could be used for job assessment as well as work redesign purposes. Such studies would eventually lead to working environments that are safer and that minimise the risk of LBP due to non-ergonomically designed workplaces.

- Further work should concentrate on the measurement of large numbers of patients with the same clinical diagnosis in order to determine how specific pathology affects lumbar mobility. If this work shows a relationship between specific pathology and mobility then clinical guidelines could be developed based on these findings. If this work reveals no

relationship between specific pathology of the lumbar spine and mobility then a return to more invasive techniques of diagnosis should be considered.

- The use of low velocity mobilisation techniques in the treatment of acute/subacute LBP by clinicians of different schools (systems) should be investigated in clinical trials involving large number of patients in order to confirm/contradict the results of this study.

THE VALIDATION AND USE OF A THREE DIMENSIONAL GONIOMETRY SYSTEM TO INVESTIGATE LUMBAR MOTION IN HEALTHY SUBJECTS AND LOW BACK PAIN PATIENTS UNDERGOING MANUAL MOBILISATION.

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Appendices

Appendix A (7.1) Patient information sheet

Queen Margaret University College
EDINBURGH established 1875

PATIENT INFORMATION SHEET

Research Project Title:
An investigation into the movement of the low back in patients receiving treatment for low back pain.

Research Project Aim:
The aim of this research project is:
1. To measure the movement in your lower back and also to see how much movement occurs during some functional activities i.e. walking, rising to stand, sitting down and picking up an object from the floor. The data will be used to establish values for low back pain patients which will be compared to values obtained in subjects without back pain.
2. We would also like to establish what effect your treatment has on the movement of your back.
To do this we would like to measure your back movements three times during your first hospital appointment. This will only occur on the first treatment day. Subsequent treatment visits will not include these measurements.

Procedure:
On arrival at the physiotherapy department you will be met by the principal investigator and asked if you are prepared to be involved in the study. If you agree to take part in the study you will be taken to a treatment room. In the treatment room we will ask you to answer some questions about your back pain and its effect on your daily activities. We will then attach a light-weight measuring device to the skin on your lower back using tape and two belts. One belt will be attached at waist level and the other at the height of the lower ribs. In order to facilitate attachment of the measuring device we would like you to wear specially prepared training trousers, and a loose fitted T-shirt. These will be provided.
The device will be demonstrated to you and its working explained before the commencement of the trial. There is no obligation to be involved and your treatment will not be affected whether you decide to be involved or not.

The different movements will be demonstrated to you.
These will be : Bending forwards from standing
Bending backwards from standing
Bending to both sides from standing
Twist to both sides from standing
Walk along a seven meter line and then return to starting point

Sitting down and standing up from a chair
Bending and picking up an object from the floor (both sides)
Bending forwards, backwards, to both sides and twist from a sitting position

You will be given time to become accustomed to the measuring device while lying on a plinth. You will then be asked to perform the test movements, at your own pace, after a "start" signal from the investigator. You are not required to carry out any of the movements if they are painful and you are free to stop at any point without consequence to you or your treatment. On completion of the tests the equipment will then be removed.

Subsequently you will be randomly allocated on an equal basis to either:
a. Receive your treatment from your physiotherapist then be remeasured by the investigator, relax quietly for 1/2 hour and be measured for a third and final time.
or
b. relax quietly for 1/2 hour then be measured by the investigator, receive your treatment from your physiotherapist and be measured for a third and final time.

The entire test and treatment session will last approximately 2 and 1/2 hours. All other visits will be as normal (approximately 1/2 hour). Should you have any questions which you wish to ask before your first session please feel free to contact me at the address given below.
All information will be confidential and will be used anonymously for research purposes only. A copy of the indemnity arrangements can be obtained on request.

An independent advisor is also available should you wish to contact her. This is:
Ms Fiona McDonald
Superintendent Physiotherapist
Department of Physiotherapy
Western General Hospital
Tel: 0131-537-1288

Principal investigator:

Guy Van Herp, MSc. MCSP, Research Student,
Physiotherapy Department, Queen Margaret College, Edinburgh
Tel: 0131-317-3661

Appendix B (7.2) Consent Form

Consent Form

Title of study

AN INVESTIGATION INTO THE MOVEMENT OF THE LOW BACK IN PATIENTS RECEIVING TREATMENT FOR LOW BACK PAIN.

I agree to take part in this study and understand that confidentiality of results is ensured.

I have read and understood the subject information sheet and this consent form.

I have had an opportunity to ask any questions about my participation.

I understand that I am under no obligation to take part in this study.

I understand that I have the right to withdraw from this study at any stage for any reason without prejudice to me or my treatment.

I am willing for my general practitioner to be notified

Name of Subject: _____

Signature of subject: Signature of investigator:

_____ _____

Date: _____ Date: _____

Name of investigator: Guy Van Herp

Address: Physiotherapy Department
Queen Margaret College
Leith Campus
Duke Street
Edinburgh

Telephone: (0131) 3173663

Appendix C (8.1)..Visual Analogue Scale (Before treatment)

Visual Analogue Scale

Before Treatment

No Pain ——————————————— **Worst possible pain**

Appendix 8.1 Visual Analogue scale before treatment

Appendix D (8.2) Visual Analogue Scale (After treatment)

Visual Analogue Scale

After Treatment

No Pain ——————————————— **Worst possible pain**

Appendix 8.2 Visual Analogue Scale after treatment

Appendix E (8.3) Roland and Morris Disability questionnaire

Roland and Morris Disability questionnaire

When your back hurts, you may find it difficult to do some of the things you normally do.

These are some sentences that people have used to describe themselves when they have back pain. When you read them, you may find that some stand out because they describe you *today.* As you read the list, think of yourself *today.* When you read a sentence that describes you today circle YES. If that sentence does not describe you today circle NO. Remember, only answer YES if you are sure that the sentence describes you today.

1	I stay at home most of the time because of my back	Yes	No
2	I change position frequently to try and get my back comfortable	Yes	No
3	I walk more slowly than usual because of my back	Yes	No
4	Because of my back, I am not doing any of the jobs that I usually do around the house	Yes	No
5	Because of my back, I use a handrail to get upstairs	Yes	No
6	Because of my back, I lie down to rest more often	Yes	No
7	Because of my back, I have to hold on to something to get out of an easy chair	Yes	No
8	Because of my back, I try to get other people to do things for me	Yes	No
9	I get dressed more slowly than usual because of my back	Yes	No
10	I only stand up for short periods of time because of my back	Yes	No
11	Because of my back I try not to bend or kneel down	Yes	No
12	I find it difficult to get out of a chair because of my back	Yes	No
13	My back is painful almost all the time	Yes	No
14	I find it difficult to turn over in bed because of my back	Yes	No
15	My appetite is not very good because of my back pain	Yes	No
16	I have trouble getting on my socks (or stockings) because of the pain in my back	Yes	No
17	I only walk short distances because of my back pain	Yes	No
18	I sleep less well because of my back	Yes	No
19	Because of my back, I get dressed with help from someone else.	Yes	No
20	I sit down for most of the day because of my back	Yes	No
21	I avoid heavy jobs around the house because of my back	Yes	No
22	Because of my back, I am more irritable and bad tempered with people than usual	Yes	No
23	Because of my back, I go upstairs more slowly than usual	Yes	No
24	I stay in bed most of the time because of my back	Yes	No

Score: Total of all items answered YES

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Appendix F (9.1) Individual data Age, Height and Mass of Healthy Subjects

			Age Information (yrs)							
			Females					Males		
n	20-29	30-39	40-49	50-59	60+	20-29	30-39	40-49	50-59	60+
1	24	39	45	52	73	22	36	45	54	65
2	26	34	45	51	66	28	34	46	54	77
3	23	38	43	55	76	23	36	48	56	67
4	27	35	41	54	76	29	34	49	53	63
5	28	33	49	54	67	23	37	45	58	68
6	22	37	45	56	69	25	37	41	54	69
7	22	33	48	58	68	22	34	48	54	63
8	22	37	48	54	74	23	32	45	52	65
9	25	39	43	53	72	24	37	47	55	62
10	26	33	42	59	73	26	39	46	59	60
Mean Age	24.5	35.8	44.9	54.6	71.4	24.5	35.6	46	54.9	65.9
s.d.	2.2	2.5	2.7	2.5	3.7	2.5	2.1	2.3	2.2	4.8
Max	28	39	49	59	76	29	39	49	59	77
Min	22	33	41	51	66	22	32	41	52	60
Ranges	6	6	8	8	10	7	7	8	7	17
			Height Information(m)							
			Females					Males		
n	20-29	30-39	40-49	50-59	60+	20-29	30-39	40-49	50-59	60+
1	1.65	1.57	1.73	1.68	1.62	1.71	1.82	1.71	1.78	1.78
2	1.70	1.75	1.66	1.68	1.59	1.85	1.75	1.81	1.87	1.76
3	1.69	1.74	1.56	1.58	1.65	1.84	1.71	1.84	1.88	1.73
4	1.67	1.65	1.62	1.66	1.69	1.85	1.78	1.75	1.67	1.70
5	1.65	1.63	1.67	1.59	1.65	1.76	1.88	1.81	1.69	1.68
6	1.69	1.64	1.73	1.67	1.63	1.80	1.76	1.79	1.72	1.65
7	1.69	1.76	1.71	1.64	1.57	1.78	1.75	1.67	1.84	1.86
8	1.63	1.67	1.58	1.56	1.59	1.73	1.75	1.80	1.73	1.69
9	1.64	1.61	1.61	1.66	1.51	1.71	1.78	1.57	1.71	1.70
10	1.70	1.62	1.62	1.61	1.55	1.78	1.85	1.67	1.74	1.79
Mean Height	1.67	1.66	1.64	1.63	1.60.	1.78	1.78	1.74	1.76	1.73
s.d.	0.26	6.5	6.1	4.4	5.4	5.4	5.2	8.5	7.6	6.3
Max	1.70	1.76	1.73	1.68	1.69	1.85	1.88	1.84	1.88	1.86
Min	1.63	1.57	1.56	1.56	1.51	1.71	1.71	1.57	1.67	1.65
Range	0.0	0.19	0.17	0.12	0.18	0.14	0.17	0.27	0.21	0.21
	7		Mass Information(kg)							
			Females					Males		
n	20-29	30-39	40-49	50-59	60+	20-29	30-39	40-49	50-59	60+
1	60	47	73	66	60	87	74	87	78	84
2	54	72	61	70	55	79	73	87	87	80
3	68	56	59	61	61	78	78	76	106	85
4	79	55	53	73	68	84	86	82	63	69
5	57	59	53	73	76	73	81	97	76	106
6	75	61	80	61	74	64	99	84	84	80
7	57	64	79	64	62	78	80	81	78	85
8	69	76	65	54	70	70	78	87	82	66
9	55	79	69	69	67	70	87	70	96	73
10	68	86	65	68	73	92	66	70	71	79
Mean Mass	64.2	65.5	65.7	65.9	66.6	77.5	80.2	82.1	82.1	80.7
s.d.	8.8	12.3	9.6	6.0	6.9	8.6	9.0	8.4	12.3	11.1
Max	79	86	80	73	76	92	99	97	106	106
Min	54	47	53	54	55	64	66	70	63	66
Ranges	25	39	27	19	21	28	33	27	43	40

Appendix 9.1 Individual data Age, Height and Mass of Healthy Subjects

Appendix G (9.2) Group Characteristics

Intervention Group Characteristics					Delayed Intervention group Characteristics				
Pat Number	Age (y)	Height (m)	Mass (kg)	Gender	Pat Number	Age (y.)	Height (m)	Mass (kg)	Gender
9a	45	1.75	66	Male	1b	21	1.7	68	Male
13a	49	1.81	81	Male	3b	64	1.77	73	Male
23a	54	1.78	91	Male	5b	48	1.78	80	Male
25a	28	1.75	90	Male	6b	53	1.79	83	Male
28a	73	1.69	82	Male	10b	70	1.69	81	Male
40a	67	1.62	66	Male	12b	51	1.62	73	Male
41a	40	1.74	67	Male	22b	47	1.92	88	Male
2a	35	1.6	60	Female	33b	51	1.81	73	Male
15a	57	1.64	69	Female	34b	49	1.78	95	Male
16a	64	1.6	64	Female	35b	42	1.72	93	Male
17a	43	1.65	110	Female	4b	46	1.65	55	Female
21a	20	1.6	59	Female	7b	53	1.63	60	Female
26a	41	1.66	56	Female	8b	45	1.63	85	Female
27a	32	1.75	72	Female	11b	41	1.59	57	Female
29a	43	1.69	62	Female	14b	20	1.94	76	Female
30a	44	1.62	72	Female	18b	44	1.57	59	Female
32a	46	1.7	51	Female	19b	23	1.65	53	Female
37a	51	1.55	83	Female	20b	31	1.7	67	Female
38a	48	1.71	75	Female	24b	37	1.65	61	Female
39a	41	1.61	62	Female	31b	54	1.52	56	Female
					36b	58	1.55	80	Female
Mean	46.05	1.68	71.90		Mean	45.14	1.70	72.19	
S.D.	12.86	0.07	14.18		S.D.	13.11	0.11	12.94	
Max.	73	1.81	110		Max.	70	1.94	95	
Min	20	1.55	51		Min	20	1.52	53	
Range	53	0.26	59		Range	50	0.42	42	

Appendix H (9.3) Manual therapy techniques used.

Technique	Physio I	Physio II	Physio III	Physio IV	Physio V	Physi o VI	Total
PA.'s L1		1		2			3
L2	1	2		2			5
L3	2	3	2	1	1		9
L4	5	3	3	5	3	1	20
L5	3	3	2	6	2	1	17
Total PA unilater L1	11	12	7	16	6	2	54
L2			1				1
L3					1		1
L4	1	2		1	2		6
L5	1	1		2	1	1	5
Total Transverse L1	2	3	1	3	4	1	13
L2		1					1
L3	3	1					4
L4	2	1		1			4
L5		1	1	1			3
Total Rotation	5 2	4 1	1 11	2 4	1	1	12 20

Appendix 9.3 Mobilisation techniques used and levels mobilised

Appendix I (9.4) Different grades used.

Technique	Physio I	Physio II	Physio III	Physio IV	Physio V	Physio VI	Total
Grade I L1							
L2			1		1		2
L3	1		1		2		4
L4	1				1		2
L5							
Rotations							
Total	2		2		3		8
Grade II L1		1			1		2
L2		2	1		3		6
L3		2	1		3		6
L4		2	4		1	7	14
L5		2	2		1	5	10
Rotations		1	4		5		10
Total		1	4		5		48
Grade III L1		1		2	3		6
L2	1	2		2	5		10
L3	4	2	2	2	10		20
L4	7	2	3	4	2	1	19
L5	3	2	3	4	2	1	15
Rotations	2	1	4	2	1	1	11
Total	17	10	12	16	23	3	81
Grade IV L1							
L2							
L3		1			1		2
L4		2	1	2	4		9
L5		1	1	2	4		8
Rotations		1	1	2	4		8
Total		5	3	6	13		27
Grade V L1							
L2							
L3							
L4							
L5			1		1		2
Rotations		1	2		3		6
Total		1	3		4		8

Appendix 9.4 Frequency of grade used by physiotherapists participating in the clinical trial.

Appendix J (12.1-12.6)

Appendix 12.1 Effect on Forward flexion excursion

Lateral Bend during Forward Flexion	**Intervention Group (n=20) (Degrees)**			**Delayed Intervention Group (n=21) (Degrees)**		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Mean	5.4	5.1	4.8	5.4	5.1	5.2
Standard Deviation	3.7	2.5	3.0	2.2	2.8	2.1
Upper 95% Conf. Limit	13.2	10.0	10.8	9.7	10.5	9.3
Lower 95% Conf. Limit	-1.4	0.2	-1.1	1.0	-0.3	1.1
Max. Value in Group	15.6	9.3	13.2	10.6	12.9	11.6
Min. Value in Group	2.0	1.2	1.0	2.6	2.3	2.2
Median	4.7	3.9	3.5	4.6	4.4	5.1
97.5th Percentile	14.1	9.1	12.0	9.8	11.6	9.9
2.5th Percentile	2.1	1.8	1.7	2.7	2.3	2.7

Table 1 Excursion values of lateral bending during forward flexion

Flexion during Forward Flexion	**Intervention Group (n=20) (Degrees)**			**Delayed Intervention Group (n=21) (Degrees)**		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Mean	41.4	39.4	38.1	44.7	39.4	44.4
Standard Deviation	14.7	13.7	14.5	12.9	10.6	14.5
Upper 95% Conf. Limit	70.2	66.3	66.5	69.9	60.3	72.8
Lower 95% Conf. Limit	12.6	12.5	9.6	19.4	18.6	15.9
Max. Value in Group	68.6	56.2	61.7	78.9	59.1	79.6
Min. Value in Group	15.6	10.3	9.5	28.9	20.5	24.3
Median	45.6	40.9	39.1	42.6	39.5	45.2
97.5th Percentile	63.5	55.5	60.1	75.9	56.7	74.4
2.5th Percentile	15.6	13.5	12.7	29.1	20.8	25.6

Table 2 Excursion values of flexion during forward flexion

Axial Rotation during Forward Flexion	Intervention Group (n=20) (Degrees)			In Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	4.5	5.0	4.6	4.7	4.5	4.9
Standard Deviation	2.0	2.4	2.1	2.0	2.2	2.6
Upper 95% Conf. Limit	8.4	9.8	8.7	8.5	8.7	10.1
Lower 95% Conf. Limit	0.6	0.2	0.5	0.8	0.2	-0.3
Max. Value in Group	9.3	11.9	10.8	10.0	8.7	12.4
Min. Value in Group	1.9	1.1	2.1	2.0	1.3	1.5
Median	4.3	4.3	4.4	4.4	4.2	3.9
97.5th Percentile	8.9	10.5	9.0	8.8	8.3	11.0
2.5th Percentile	2.0	1.9	2.3	2.1	1.5	1.8

Table 3 Excursion values of axial rotation during forward flexion

Appendix 12.2 Effect on Extension Excursion

Lateral Bend during Extension	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	3.4	3.4	2.9	2.7	2.9	3.5
Standard Deviation	3.2	1.6	1.0	1.0	1.4	1.5
Upper 95% Conf. Limit	9.6	6.5	4.9	4.7	5.6	6.5
Lower 95% Conf. Limit	-2.8	0.2	0.9	0.7	0.1	0.5
Max. Value in Group	16.1	8.5	4.6	4.5	6.9	6.7
Min. Value in Group	1.1	1.2	0.9	1.1	0.9	1.3
Median	2.7	3.2	2.9	2.8	2.6	3.4
97.5th Percentile	10.6	6.9	4.4	4.5	5.7	6.2
2.5th Percentile	1.1	1.3	1.3	1.2	1.0	1.5

Table 4 Excursion values of lateral bending during extension

Extension during Extension movement	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	14.5	15.6	15.6	16.8	16.6	18.5
Standard Deviation	9.0	8.4	8.7	9.5	9.1	9.4
Upper 95% Conf. Limit	32.2	32.1	32.6	35.5	34.4	37.0
Lower 95% Conf. Limit	-3.2	-1.0	-1.5	-1.9	-1.3	0.1
Max. Value in Group	39.6	33.6	34.9	46.0	36.7	37.5
Min. Value in Group	3.7	3.6	3.5	6.4	5.5	7.1
Median	12.7	14.6	16.4	15.2	14.5	15.6
97.5th Percentile	35.5	31.5	32.8	39.2	36.3	37.4
2.5th Percentile	3.9	3.9	3.8	6.6	5.8	8.0

Table 5 Excursion values of extension during extension.

Axial Rotation during Extension	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Mean	3.6	3.5	3.3	3.4	3.1	4.0
Standard Deviation	3.4	2.2	1.8	1.9	1.4	1.6
Upper 95% Conf. Limit	10.2	7.8	6.9	7.1	5.9	7.2
Lower 95% Conf. Limit	-3.2	-0.8	-0.3	-0.4	0.3	0.8
Max. Value in Group	16.5	9.9	8.2	8.9	5.7	8.3
Min. Value in Group	1.0	1.3	1.7	1.0	1.2	1.8
Median	2.7	3.2	2.6	2.8	2.8	3.9
97.5th Percentile	12.2	8.1	7.7	7.6	5.7	7.3
2.5th Percentile	1.2	1.3	1.7	1.4	1.2	1.9

Table 6 Excursion values of axial rotation during extension

Appendix 12.3 Effect on Lateral Bending to the Left

Lateral Bend during Lat. Bend to the Left	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	16.4	16.4	17.4	19.9	19.8	20.6
Standard Deviation	6.9	6.6	8.2	6.0	6.5	6.5
Upper 95% Conf. Limit	30.0	29.6	33.4	31.7	32.6	33.4
Lower 95% Conf. Limit	2.9	3.5	1.3	8.0	7.0	7.8
Max. Value in Group	29.2	26.5	38.5	34.1	34.0	34.5
Min. Value in Group	4.1	4.9	2.0	8.9	9.8	10.2
Median	15.6	16.4	18.1	19.8	18.3	19.4
97.5th Percentile	29.2	26.5	33.4	31.6	31.8	32.8
2.5th Percentile	4.9	6.1	3.7	10.4	10.3	12.1

Table 7 Excursion values of lateral bending during lateral bending to the left

Flexion & Lat. Bend to the Left	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	10.7	11.9	12.1	9.8	10.3	10.7
Standard Deviation	8.3	7.1	7.0	4.5	4.1	5.2
Upper 95% Conf. Limit	26.9	25.9	25.8	18.7	18.3	20.8
Lower 95% Conf. Limit	-5.5	-2.2	-1.6	0.9	2.2	0.5
Max. Value in Group	35.1	25.8	23.4	19.6	17.9	23.8
Min. Value in Group	2.1	2.0	2.6	3.1	5.2	2.5
Median	8.4	10.6	10.0	9.9	9.7	10.2
97.5th Percentile	28.8	25.4	23.2	17.9	17.8	20.7
2.5th Percentile	2.2	2.4	3.0	3.4	5.3	3.4

Table 8 Excursion values of flexion during lateral bending to the left

Axial Rotation & Lat. Bend to the Left	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Mean	4.7	4.1	5.4	5.3	5.5	5.4
Standard Deviation	2.3	1.8	2.2	1.8	2.7	2.3
Upper 95% Conf. Limit	9.3	7.7	9.8	8.7	10.8	9.9
Lower 95% Conf. Limit	0.1	0.6	1.0	1.8	0.3	1.0
Max. Value in Group	9.2	8.1	10.3	9.2	9.9	11.5
Min. Value in Group	1.6	1.4	1.9	1.7	1.8	1.6
Median	3.7	3.8	4.9	5.1	4.6	5.1
97.5th Percentile	9.0	7.5	9.7	9.0	9.8	10.2
2.5th Percentile	2.0	1.7	2.3	1.9	2.1	2.0

Table 9 Excursion values of axial rotation during lateral bending to the left

Appendix 12 4 Effects on Lateral Bending to the Right

Lateral Bend & Lat. bend to the Right	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	17.7	18.1	18.4	20.6	20.4	21.5
Standard Deviation	7.2	6.8	7.1	7.3	6.8	7.1
Upper 95% Conf. Limit	31.8	31.3	32.3	34.5	33.7	35.3
Lower 95% Conf. Limit	3.5	4.8	4.5	6.0	7.1	7.6
Max. Value in Group	30.1	29.4	32.1	37.1	35.4	37.5
Min. Value in Group	6.1	5.0	5.3	9.6	8.4	10.9
Median	17.7	17.0	20.3	18.7	19.4	20.7
97.5th Percentile	28.9	29.4	30.4	34.6	33.3	36.4
2.5th Percentile	6.5	6.4	7.0	10.4	10.6	10.9

Table 10 Excursion values of lateral bending during lateral bending to the right

Flexion & Lat. Bend to the Right	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	10.1	10.1	9.6	10.5	9.2	10.7
Standard Deviation	7.6	5.8	6.9	4.5	3.9	5.2
Upper 95% Conf. Limit	25.0	21.5	23.1	19.6	16.8	20.8
Lower 95% Conf. Limit	-4.7	-1.3	-3.8	1.6	1.7	0.5
Max. Value in Group	27.0	25.9	29.4	19.3	16.8	21.1
Min. Value in Group	2.5	2.9	1.6	3.3	3.1	4.2
Median	8.0	9.4	8.1	11.1	9.1	9.7
97.5th Percentile	26.5	23.4	23.9	18.8	15.5	20.5
2.5th Percentile	2.7	3.3	2.2	3.8	3.3	4.7

Table 11 Excursion values of flexion during lateral bending to the right

Axial Rotation during Lat. bend to the Right	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Mean	4.5	4.7	4.7	5.5	5.0	5.1
Standard Deviation	2.7	2.3	2.3	2.6	2.3	2.3
Upper 95% Conf. Limit	9.8	9.2	9.2	10.5	9.6	9.6
Lower 95% Conf. Limit	-0.8	0.2	0.1	0.4	0.5	0.7
Max. Value in Group	9.8	10.7	11.9	10.4	9.8	9.2
Min. Value in Group	1.5	1.9	0.8	1.6	1.7	2.0
Median	3.6	4.4	4.2	4.9	4.3	4.9
97.5th Percentile	9.7	10.2	9.9	10.0	9.4	8.9
2.5th Percentile	1.5	1.9	1.8	1.7	1.9	2.3

Table 12 Excursion values of axial rotation during lateral bending to the right

Appendix 12.5 Effects on Axial Rotation to the Left

Lateral Bend during Axial Rot. to the Left	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	4.0	3.9	4.9	4.6	5.2	5.4
Standard Deviation	2.1	1.8	3.6	2.0	2.0	2.5
Upper 95% Conf. Limit	8.2	7.4	11.9	8.5	9.0	10.3
Lower 95% Conf. Limit	-0.1	0.4	-2.1	0.8	1.3	0.5
Max. Value in Group	10.2	7.2	14.7	8.3	9.7	10.5
Min. Value in Group	1.3	0.7	0.6	1.9	2.4	1.9
Median	3.6	3.4	3.8	4.5	5.0	4.9
97.5th Percentile	9.0	7.1	12.9	8.1	8.8	10.3
2.5th Percentile	1.4	1.1	1.2	2.0	2.5	2.1

Table 13 Excursion values of lateral bending during axial rotation to the left

Flexion-Extension during Axial Rot to the Left	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	7.1	7.8	6.9	6.1	7.6	6.8
Standard Deviation	4.0	5.0	3.5	3.8	3.7	3.4
Upper 95% Conf. Limit	14.9	17.7	13.7	13.6	14.9	13.5
Lower 95% Conf. Limit	-0.7	-2.1	0.1	-1.3	0.4	0.1
Max. Value in Group	12.8	21.0	13.5	20.2	16.6	15.8
Min. Value in Group	1.1	1.6	1.3	2.7	1.5	2.1
Median	6.0	6.5	6.6	5.3	7.0	6.3
97.5th Percentile	12.7	18.4	13.0	15.0	14.5	14.0
2.5th Percentile	1.3	2.1	2.2	2.8	1.8	2.2

Table 14. Excursion values of flexion during axial rotation to the left

Axial Rotation during axial rotation to the Left	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Mean	11.7	13.0	11.6	13.1	14.3	15.4
Standard Deviation	6.4	6.4	5.6	5.6	6.0	5.8
Upper 95% Conf. Limit	24.1	25.4	22.5	24.1	26.1	26.8
Lower 95% Conf. Limit	-0.8	0.5	0.6	2.2	2.5	4.1
Max. Value in Group	29.7	26.9	21.2	24.0	25.0	28.8
Min. Value in Group	1.8	2.0	2.1	5.5	4.9	7.8
Median	9.7	12.5	11.4	14.2	13.1	14.5
97.5th Percentile	25.2	25.4	21.1	22.5	24.5	27.2
2.5th Percentile	2.9	3.0	2.7	5.7	5.2	7.9

Table 15 Excursion values of axial rotation during axial rotation to the left

Appendix 12.6 Effects on Axial Rotation to the Right

Lateral Bend during Ax. rot. to the Right	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	5.0	4.6	5.0	4.7	4.6	4.7
Standard Deviation	3.7	2.5	2.4	1.5	2.3	2.6
Upper 95% Conf. Limit	12.4	9.5	9.6	7.6	9.2	9.9
Lower 95% Conf. Limit	-2.3	-0.2	0.3	1.9	0.1	-0.5
Max. Value in Group	18.6	10.9	11.5	7.6	10.9	10.3
Min. Value in Group	1.4	0.8	1.0	2.5	1.9	1.9
Median	4.3	4.2	5.0	4.6	3.9	4.0
97.5th Percentile	13.5	10.1	9.8	7.2	10.2	10.1
2.5th Percentile	1.7	1.3	1.5	2.6	1.9	1.9

Table 16 Excursion values of lateral bending during axial rotation to the right

Flexion-Extension during Axial Rot. to the Right	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
Mean	5.1	5.8	5.6	7.1	5.8	7.1
Standard Deviation	2.2	2.9	3.2	4.3	2.9	4.5
Upper 95% Conf. Limit	9.5	11.5	11.8	15.5	11.4	15.9
Lower 95% Conf. Limit	0.8	0.1	-0.7	-1.4	0.2	-1.7
Max. Value in Group	9.0	12.0	14.7	16.8	13.5	21.2
Min. Value in Group	1.2	2.1	2.6	1.7	1.9	1.6
Median	5.4	5.1	5.0	6.3	5.7	5.2
97.5th Percentile	8.3	11.5	13.5	15.7	11.4	16.8
2.5th Percentile	1.4	2.4	2.6	1.9	1.9	2.3

Table 17. Excursion values of forward flexion during axial rotation to the right

Axial Rotation during Axial Rot. to the Right	Intervention Group (n=20) (Degrees)			Delayed Intervention Group (n=21) (Degrees)		
	Test 1	**Test 2**	**Test 3**	**Test 1**	**Test 2**	**Test 3**
Mean	10.4	13.9	11.9	12.3	13.2	12.9
Standard Deviation	4.9	6.5	5.5	6.0	5.6	5.7
Upper 95% Conf. Limit	19.9	26.6	22.7	24.1	24.2	24.0
Lower 95% Conf. Limit	0.9	1.1	1.0	0.5	2.1	1.7
Max. Value in Group	19.0	24.6	25.7	28.6	28.8	25.2
Min. Value in Group	2.4	2.4	1.8	6.4	6.1	5.0
Median	10.5	14.2	10.8	10.8	12.3	11.5
97.5th Percentile	18.5	24.4	22.8	25.9	26.7	23.3
2.5th Percentile	3.1	3.1	4.1	6.5	6.7	5.1

Table 18 Excursion values of axial rotation during axial rotation to the right